UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE PALISADES DAM OUTLET WORKS AND SPILLWAY PALISADES PROJECT - IDAHO

Hydraulic Laboratory Report No. Hyd-350

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

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Commissioner's Office, Denver
Division of Engineering Laboratories
Hydraulic Laboratory Branch
Hydraulic Structures & Equipment Section
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Laboratory Report No. HYD-350
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Subject: Hydraulic model studies of the Palisades Dam Outlet Works and Spillway--Palisades Project, Idaho

PURPOSE

Studies to investigate the hydraulic characteristics of preliminary designs and to assist in determining any changes that would ensure hydraulically satisfactory spillway and outlet works structures.

The studies evaluated the flow conditions in the concrete-lined diversion channels, the outlet and power tunnels, the outlet piping system, the outlet stilling basins, the spillway entrance, the spillway tunnel, the spillway exit channel, and the downstream river channel.

CONCLUSIONS

River Diversion

1. Water diverted during construction through the outlet tunnel and its lined diversion channel will spread evenly in the channel to a maximum discharge of 26,000 cfs without seriously overtopping the right-hand wall with its top at elevation 5397.0 or the left-hand wall with its top at elevation 5400.0.

2. The power tunnel diversion channel will handle an approximate maximum discharge of 18,000 cfs when a temporary deflector wall with its top at elevation 5400.0 is extended from the right side of the power tunnel exit to the wall of the diversion channel lining about 140 feet downstream (Figure 10).

3. The flow conditions in the prototype diversion channels at the maximum discharges should not cause damage to the channel linings.

The Outlet Works

1. A piping system for the main outlet works using 2 hollow-jet valves and 4 rectangular slide gates will satisfactorily handle the discharge from the outlet tunnel (Figure 14).

2. The distribution of the discharge in the stilling basin chute will be satisfactory with the 8.5-foot long walls of the downstream frames of the slide gates made parallel and spaced 7.5 feet apart (Figure 13B).

3. Cavitation pressures would occur in the preliminary constant diameter branch of the 2-way Y's upstream of the slide gates when one gate was fully open and the other gate fully closed, (Figures 15B and 16A).

4. Cavitation will not occur in the constant diameter branches upstream of the hollow-jet valves because of the relatively high pressure upstream of this type valve.

5. A 5-degree, 48-minute, 13-second converging branch of the 2-way Y upstream of the slide gates will prevent cavitation pressures for one or both slide gates fully opened (Figures 14 and 15B).

6. The discharge from the fully opened valves and gates will be distributed 22.6 percent to the hollow-jet valves and 77.4 percent to the four slide gates.

7. The use of a coefficient of discharge of 0.57 in the equation $Q = CA\sqrt{2gH}$ will give the discharge capacity of the outlet works with gates and valves fully opened. This coefficient is based on the area of the 26-foot diameter tunnel and the total head at a distance of 262 feet upstream of the gate exits.

8. The use of a coefficient of discharge of 0.24 in the equation $Q = CA\sqrt{2gH}$ will give the discharge capacity of the power tunnel outlet gates fully opened. This coefficient is based on the area of the 26-foot diameter power tunnel and the total head at a distance of 203 feet upstream of the valve exits.

9. With symmetrical operation of the outlet tunnel and power tunnel gates, the preliminary stilling basin would be effective in dissipating the energy of the water. Unsymmetrical operation of the gates would create waves that overtop the training walls and would form eddies that could bring material upstream into the stilling basin.

10. Two additional dividing walls in the stilling basin will stabilize the flow in the basin so that unsymmetrical releases can be made.

11. Chute blocks located at the junction of the chute and stilling basin floor, and floor blocks located 69.5 feet downstream of the chute blocks are required for good energy dissipation in the stilling basin (Figure 18).

12. Sweep out of the jump will not occur until the tail-water elevation is lowered 4 feet or more below the computed normal elevation of 5380.3 for a discharge of 30,550 cfs, and 6.5 feet or more below the computed normal elevation for a discharge of 46,100 cfs.

13. The exit channel of the stilling basin can be adequately protected by 3-foot dumped riprap.

Tunnel Spillway

1. Good flow conditions would occur in the preliminary design spillway entrance with the 40-foot radius entrance piers. The design of the piers was modified during the test program to make them smaller and to reduce their cost.

2. The recommended right- and left-hand entrance piers, with a section profile of an ellipse $\left(\frac{X^2}{(30)^2} + \frac{Y^2}{(12.5)^2} = 1\right)$ and a 7.5-foot radius at the upstream end will be satisfactory for all discharges, including the design maximum of 48,400 cfs. However, the turbulence within the spillway and in the first part of the tunnel is somewhat greater than in the preliminary design (Figure 24A).

3. A center pier in the spillway entrance that extends from approximately Station 4+70 to Station 5+90 and tapers in the last 60 feet from a thickness of 6 feet to 3 feet will give satisfactory flow conditions in the tunnel for discharges to 48,400 cfs for both 1- and 2-gate operation (Figures 24, 25, and 27).

4. The 26-foot diameter tunnel of the preliminary design would be inadequate for the design discharge of 48,400 cfs.

5. A diameter of 28 feet will give the tunnel adequate capacity for the design discharge of 48,400 cfs.

6. Air entrained by the water in the 28-foot prototype tunnel may increase the resistance to flow and there may be a tendency for the tunnel to flow full to the lower bend for discharges near the maximum.

7. An increase in tail water up to 14 feet above the computed normal elevation for a discharge of 48,400 cfs from the spillway should not in itself cause the tunnel to flow full.

8. The preliminary design of the transition from the circular tunnel exit to the trapezoidal channel lining would be unsatisfactory because water would overtop the channel walls (Figure 22D).

9. A transition from the spillway tunnel to the exit channel that begins at Station 24+00 with a circular cross section; changes to a horseshoe shape at the tunnel exit, Station 24+46.35; and is the trapezoidal shape of the channel at Station 25+20; will provide a smooth transition of flow from the tunnel to the exit channel (Figures 24 and 28).

10. The upward curve of the floor at the end of the lined channel directs the high-velocity flow upward and over the rock foundation.

11. The maximum capacity for the spillway with a reservoir elevation of 5621.0 is 48,400 cfs. This is indicated by the calibration data from the 1:61.82 scale model (Figure 31).

RECOMMENDATIONS

1. Release water from valves and gates on alternate sides of the basin centerline for the best energy dissipation in the stilling basin.

2. Investigate the performance of the 7 foot 6 inch by 9 foot 0 inch slide gates by using them for regulation at partial openings. Satisfactory performance will permit symmetrical operation of the basin.

3. Operate spillway radial gates at equal openings to provide symmetrical flow distribution in the spillway tunnel.

4. Use capacity curves of Figure 31 to determine the spillway discharge.

ACKNOWLEDGEMENT

Engineers of the Dams Branch and of the Hydraulic Laboratory Branch jointly developed the design of the hydraulic features of Palisades Dam.

INTRODUCTION

Palisades Dam and reservoir are located approximately 70 miles northeast of Pocatello, Idaho, on the south fork of the Snake River (Figure 1). The dam is a rock-faced, earth-filled structure having a length of approximately 2,200 feet and a height of about 225 feet above the river channel (Figure 2). The reservoir is used for flood control and to supply water for irrigation and for electric power. Water releases from the reservoir are made through the turbines of the powerplant, through the outlet works, or through the tunnel spillway; all located at the left abutment of the dam. Normal river flows pass through the turbines or through two 96-inch hollow-jet valves of the outlet works. Floods are discharged through the outlet works or through the tunnel spillway which is approximately 200 feet to the left of the outlet works.

Water flows from the reservoir through a bellmouth entrance into the 26-foot diameter outlet tunnel which is lined with concrete for approximately 692 feet of its length, and with steel for the remaining 732 feet. The tunnel branches at Station 17+58 into two 16-foot diameter pipes and one 13-foot diameter pipe (Figure 14). The 13-foot pipe on the tunnel centerline branches into two 8-foot diameter pipes which terminate with 96-inch hollow-jet valves. The two 16-foot pipes branch into two 9-foot 6-inch diameter pipes which terminate with 7-foot 6-inch wide by 9-foot 0-inch high rectangular slide gates. These slide gates are discussed in Report No. Hyd-387. A maximum discharge of approximately 33,000 cfs from the valves and slide gates empties into the left 104-foot wide section of the 158-foot wide concrete-lined stilling basin (Figure 18).

Two 7-foot 6-inch by 9-foot 0-inch rectangular slide gates discharge approximately 11,500 cfs from the power tunnel penstock into the remaining 54 feet of basin width (Figure 18). Water from the two tunnel systems flows down a parabolic chute 174 feet long into the stilling basin. The floor of the stilling basin is at elevation 5345.0 and the training wall height is 55 feet. Chute blocks 6.75 feet high by [illegible] feet wide are located at the junction of the chute and basin floors, and a 5-foot high sill on a 2:1 slope is located on the floor at the exit of the basin. Three walls with top elevation 5378.50 divide the chute and stilling basin and direct the flow of water from pairs of gates and valves to the stilling basin. One of these walls separates the outlet works flow from that of the power tunnel outlets.

Flood discharges exceeding the capacity of the outlet works are released through two 20-foot wide by 50-foot high radial gates over a 40-foot long crest at elevation 5570.0 (Figure 2). Water flows over the crest, through a transition, a vertical bend, inclined tunnel, another vertical bend, and through a 28-foot diameter tunnel. The difference in elevation between the crest and the tunnel invert at the end of the second bend is 167 feet. The horizontal distance between the crest at Station 5+00 and the end of the bend is 272 feet. The point, Station 19+15, in the floor of the outlet tunnel diversion channel was elevation 5378.25. The highest point in the power tunnel channel was 4.25 feet lower at elevation 5374.00 (Figure 4, Detail C).

Model flows representing discharges to 18,500 cfs from each tunnel did not seriously overtop the outside or dividing walls of the preliminary design (Figure 5A). However, a discharge representing 33,000 cfs, the design maximum for the power tunnel, overtopped the dividing wall in quantities that would interfere with construction in the adjacent outlet diversion channel (Figure 5B).

Modifications to outlet tunnel diversion channel. The wall dividing the outlet and power tunnel diversion channels was raised from elevation 5390.0 to 5400.0. A flow of 25,500 cfs could under certain circumstances be discharged through the outlet diversion channel without overtopping either the outside walls or the dividing wall (Figure 5C). However, the flow direction was not stable and the flow intermittently shifted to the left or right of the channel centerline and overtopped the walls (Figures 5D and E). The flow direction was stabilized in the basin for discharges up to 23,500 cfs by constructing a wedge at the right side of the tunnel exit (Figure 4, Detail A).

The floor of the channel downstream from Station 19+15 was to be constructed to a parabolic shape starting at elevation 5378.25, and a temporary upslope was provided ahead of the parabola (Figure 4, Detail B). After diversion was completed, the slope was to be replaced by a horizontal 15-foot long floor that would receive the jets discharged from the outlet works valves. Subsequent tests of the valves disclosed that the flat section was not needed and that the parabola origin could be moved upstream 15 feet to Station 19+00. All pressures measured on the original chute were above atmospheric, and the preliminary outlet channel with the center wall raised to elevation 5400.0, and with the wedge at the tunnel outlet, was considered satisfactory for diversion.

Modifications to power tunnel diversion channel. The centerline of the power tunnel was located approximately 55 feet to the right of the centerline of the power tunnel diversion channel (Figure 4). To divert the water from the tunnel to the channel, a temporary deflector wall was needed between the end of the tunnel and the right diversion channel wall (Figure 4). This wall was to be removed to permit completion of the power conduit after diversion was completed. With the top of the center wall at elevation 5400.0, a flow of 26,000 cfs was handled successfully (Figure 6A). When the floor of the power tunnel diversion channel was built up from its preliminary shape to the same shape as the floor in the outlet channel (Figure 4), the increased elevation caused flows of 18,000 or more cfs to submerge the tunnel exit and overtop both side walls. Serious overtopping occurred at a discharge of 27,700 cfs (Figure 6B).

The channel floor was lowered again to elevation 5374.00 and a longer deflector wall was extended from the exit portal of the power tunnel to the right wall of the stilling basin to give a flatter angle of impingement to the tunnel flow. This design was satisfactory for discharges to 26,000 cfs (Figure 6C). The discharge capacity was increased to 32,000 cfs without overtopping the walls by placing a deflector pier (Figure 4, Detail D) in the basin at Station 18+00 near the center of the channel (Figure 6D).

Conclusion of diversion channel investigation. Major changes were made by the designers of the outlet diversion channel between Stations 17+44 and 19+00.25 in which the wall divergence between the tunnel exit and the channel was made symmetrical and more gradual (Figure 7). The top of the dividing wall was lowered from elevation 5400.0 to elevation 5397.0 and the floor was sloped upward to elevation 5374.0. No model tests were made on this design, but it is expected that the flow will be stable in the symmetrical channel with the upward sloping floor, and that the dividing wall will provide ample freeboard for discharges to 26,000 cfs. Figure 8A shows a flow of 26,000 cfs in a generally similar channel design.

A change was also proposed for the power tunnel diversion channel in which the right side wall started at Station 18+90.42 instead of at Station 18+50.00. This required a change in the temporary deflector wall, and three wall angles were studied to determine the effect on the flow conditions in the channel. Photographs and the water-surface profile measurements were obtained at model discharges representing 13,000, 18,000 and 23,000 cfs (Figures 8, 9, 10, and 11).

The flow with the shortest wall was quite turbulent with waves along both walls of the channel caused by the stream from the power tunnel impinging on the deflector wall and on the raised portion of the channel floor at Station 18+83.92. The increase of turbulence over that of the preliminary design was caused by the increased angle of the deflector wall with respect to the tunnel centerline.

In general, the smaller the angle of the deflector wall with respect to the tunnel centerline, the lower the water surface elevation along both walls (Figure 11). The maximum height of water along the left wall occurred between Stations 18+80 and 19+00 for all flows. The region of maximum water surface elevation along the right wall moved upstream as the angle of the deflector wall decreased.

With the short deflector wall (Wall 1, Figure 11D), the region of highest water surface along the right wall was at Station 18+50 (Figure 8). With the intermediate wall (Wall 2, Figure 11D), this region moved upstream to Station 18+15 (Figure 9). With the long wall (Wall 3, Figure 11D), the region of highest water surface was at Station 17+90 (Figure 10). Of the three deflector walls proposed for the power tunnel diversion, the longest wall with its upstream end at Station 17+44, resulted in the most satisfactory flow conditions. With this wall the discharge through the power tunnel channel must be limited to approximately 18,000 cfs to prevent overtopping the lining.

The final decision on the construction and location of the deflector wall was to be made by the contractor and contracting officer during construction of the diversion channels.

The results of the diversion studies were published in an Interim Report, Hyd-345, "Hydraulic Model Study of the Penstock and Outlet Diversion Channels--Palisades Dam--Palisades Project," to assist in the diversion of the river flow during construction.

The Outlet Works

Outlet Works Piping System

Preliminary piping system. The preliminary piping system consisted of two branches from the power penstock and two 3-way Y's with five branches from the outlet tunnel (Figure 12A). Seven 7-1/2-foot wide by 9-1/2-foot high rectangular slide gates were placed at the ends of these seven branches. The five gates that received their flow from the outlet tunnel released the flow into the left 104-foot wide section of the stilling basin (Figure 12B). The two gates that received their flow from the power penstock released it into the right 54-foot wide section of the stilling basin. The planned operation was that all normal outlet releases would be made through the five outlet tunnel gates with the gates operating at equal openings. The two gates on the power penstock would be operated only when the powerplant was inoperable.

The piping system for this gate arrangement appeared to be satisfactory. However, because the gates were a new development and had not been proven by field operation, the arrangement was later changed to replace one slide gate with two hollow-jet valves for regulation of small discharges. This arrangement was contained in the model and tested. The results will be discussed in subsequent sections of this report.

During the preliminary tests, it was noted that the jets from adjacent gates spread to contact each other and form large fins in the chute. It was believed that the rate of divergence of the gate frames was a contributing factor in this jet interference and tests were made to find the gate frame design that would produce good flow conditions on the basin chute.

Spreading of gate jets in chute. The walls of the preliminary downstream gate frames were 8 feet 6 inches long and diverged 8 degrees relative to the centerline. This divergence allowed the jet at both sides of the gate to spread rapidly so that adjacent jets ran into each other to produce high fins of water. This resulted in an unequal distribution of discharge per foot of width in the chute and a reduction in the effectiveness of the stilling basin.

The most desirable flow condition would be to spread the jets to a uniform depth across the basin at the beginning of the jump. An optimum angle of the gate frame walls was determined by studying diverging angles of 8°, 4°, 0°, and a converging angle of 2°. An angle of 4° still permitted considerable jet interference (Figure 13A). As the angle of divergence was decreased through 0° to 2° converging, the interference due to the spreading of adjacent jets diminished. Practically no spreading occurred with the 2° converging walls. The best spreading and chute flow conditions for the outlet tunnel gates full open were obtained with gate frames having parallel walls (Figure 13B). The parallel-walled gate frames are therefore recommended for use on the prototype gates.

Modified outlet works piping system with two hollow-jet valves. In an investigation of a 1:19 scale model of the rectangular regulating slide gate, Hydraulic Laboratory Report No. Hyd-387, "Hydraulic Model Studies of the 7-foot 6-inch by 9-foot 0-inch Palisades Regulating Slide Gate", it was determined that a reduction in gate size from the preliminary 7.5 feet by 9.5 feet dimensions to 7.5 feet by 9.0 feet could be made without reducing the discharge below the required quantity. Four gates of the smaller size and two 96-inch hollow-jet valves were incorporated in a modified outlet works piping system--the two hollow-jet valves replacing the originally planned center slide gate (Figure 14).

The hollow-jet valves were included for the regulation of moderate flow increments because the slide gate design was a new development and had not been proven by field operation. Normal flows from the reservoir through the outlet works will be controlled by the hollow-jet valves. Discharges in excess of the capacity of the hollow-jet valves will be discharged through fully open slide gates.

Pressures in outlet works piping system. Subatmospheric pressures occurred in the 2-way Y's of the 1:61.82 scale model near the junction of the branches when one gate was closed and the other fully opened. A larger model on a scale of 1:32 was built of the preliminary 2-way Y design for an investigation of the critical pressure area (Figure 15B, 2-way Y No. 1). The 1:32 scale model confirmed that subatmospheric pressures of sufficient intensity to produce cavitation would occur in the prototype. This subatmospheric pressure occurred in the "crotch" of the Y at the inside of the constant diameter branch just downstream of the junction of the 16-foot diameter pipe and the 9.5-foot diameter branch pipes during single gate operation. This 2-way Y was therefore unsatisfactory for use with the proposed slide gates because fully opened single gate operation was expected.

Pressure factors were computed from measured pressures to determine the operating characteristics of the prototype 2-way Y and to compare with other designs. The equation used in these computations was:

$$\text{Pressure factor} = \text{P.F.} = \frac{h - h_e}{\frac{V_e^2}{2g}}$$

where

h is the pressure at any given piezometer, feet of water

h_e is the pressure in the pipe downstream of the 2-way Y (Figure 16A)

$\overline{V}_e$ is the Q/A_e value of the velocity in the pipe downstream of the 2-way Y

The pressure factors were computed for discharge into atmospheric pressure, but the factors also apply when the discharge is controlled by valves or gates. In these cases, the pressures in the branch may be computed if the coefficient of discharge, C, of the control device is known. The pressure at the end of the Y branch will be the back pressure due to the control, $h_e = (\frac{1}{C^2} - 1)\frac{\overline{V}_e^2}{2g}$ plus the pipeline losses from the end of the Y-branch to the control. The losses would be small if the control is attached at or near the end of the Y-branch. The value of h_e may be substituted in the pressure factor equation to obtain the pressure at any given piezometer within the branch. As an example, for a discharge through one branch with the other closed, assume:

$$Q = 7,000 \text{ cfs}$$

$$A_e = 70.9 \text{ ft}^2$$

$$\overline{V}_e = 98.8 \text{ ft per sec}$$

$$\frac{\overline{V}_e^2}{2g} = 151.4 \text{ ft of water}$$

For a control at the end of the branch with a coefficient C = 0.92

$$h_e = (\frac{1}{C^2} - 1)\frac{\overline{V}_e^2}{2g} = (\frac{1}{0.92^2} - 1)\frac{\overline{V}_e^2}{2g}$$

$$h_e = 0.182 \times 151.4 = 27.5 \text{ ft of water}$$

To obtain the pressure in the pipe at the entrance to the Y-branch, this value is used in the pressure factor equation along with the pressure factor of 0.97 for the piezometer at the entrance to the Y-branch (Figure 16A).

$$\text{P.F.} = 0.97 = \frac{(h - h_e)}{\frac{\overline{V}^2}{2g}}$$

from which the inlet pressure,

$$h = 0.97 \times 151.4 + 27.5 = 173.8 \text{ feet of water}$$

Using the same method of computation it was found that cavitation pressures would occur in the "crotch", or critical area, of the Y-branches that are located upstream of the slide gates which have high capacities and, hence, high discharge coefficients. Because of the lower discharge coefficient and resulting higher back pressure from the hollow-jet valves, the pressures in the "crotch" of the Y-branch upstream from these valves would be above vapor pressure and no cavitation would occur. Therefore, no change in the design of this 2-way Y was contemplated (Figure 16A). It was necessary, however, to change the 2-way Y branches upstream of the slide gates to eliminate the cavitation pressures, thus the study was extended.

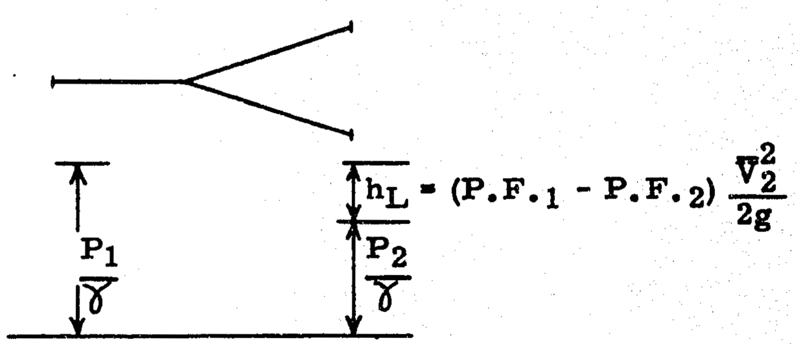
<u>Two-way Y with 9°00'17" converging passages.</u> A second 2-way Y was tested. (Figure 15B, 2-way Y No. 2.) This design had converging passages with conic angles of 9°00'17". Pressures were above atmospheric in all areas except just downstream of the point where the last conic sections of the branches joined the 9.5-foot diameter pipes (Figure 16B). This abrupt angle at the junction caused a pressure reduction sufficient to produce cavitation and the branch was not satisfactory (Area C. Figure 16B).

<u>Two-way Y with 5°48'13" converging passages--recommended design.</u> A third 2-way Y design resulted in acceptable pressures (Figure 15B, 2-way Y No. 3). The 5°48'13" conic angle resulted in a longer convergent passage and a less abrupt change in boundary alinement where the last conic section joined the 9.5-foot diameter pipe. A slight subatmospheric pressure occurred just downstream of the junction on the inside surface of the 9.5-foot pipe. The pressure was not low enough to indicate cavitation pressures in the prototype. Further studies were made on this 2-way Y to record pressure factors for conditions representing one or both gates fully opened. Pressure factors (Figure 16C) were obtained for operating conditions, as follows:

a. Both 9.5-foot pipes discharging to atmospheric pressure (no controls on ends of pipes)
b. One 9.5-foot pipe discharging to atmospheric pressure, other pipe closed
c. Both 9.5-foot pipes lengthened 1 foot (model) discharging to atmosphere. A 0.375-inch tube in the Y represented a 12-inch diameter tension bar
d. One pipe discharging to atmospheric pressure through lengthened pipe, other pipe closed, and the 12-inch diameter tension bar in place
e. One pipe lengthened 2 feet (model) discharging to atmospheric pressure, other pipe closed, and tension bar in place

Pressure factors for a and b above are applicable to small structures that handle water at high velocities and low pressures and do not need the tension bar for structural strength (Figure 16C). Pressure factors for c, d, and e are applicable to large structures that require the tension bar (Figure 16C). Pressures measured on the tension bar were above atmospheric for all flow conditions.

By use of the pressure factors the head loss for the 2-way Y, without the tension bar, in terms of the exit velocity head, was determined with both gates fully opened.



Total head at 1

$$H_1 = \frac{P_2}{\gamma} + (P.F._1 - P.F._2)\frac{V_2^2}{2g} + \frac{V_1^2}{2g}$$

Since $Q = 2Q_2$

then $A.V. = 2\,A_2V_2$

and $\frac{V_1^2}{2g} = 0.497\,\frac{V_2^2}{2g}$

then $H_1 = \frac{P_2}{\gamma} + (P.F._1 - P.F._2)\frac{V_2^2}{2g} + 0.497\,\frac{V_2^2}{2g}$

Total head at 2

$$H_2 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$$

Head loss 1 to 2

$$h_L = H_1 - H_2$$

$$h_L = \frac{P_2}{\gamma} + (P.F._1 - P.F._2)\frac{V_2^2}{2g} + 0.497\frac{V_2^2}{2g} - \frac{P_2}{} - \frac{V_2^2}{2g}$$

$$P.F._1 - P.F._2 = 0.646 - 0.004 = 0.642 \text{ (Figure 16D)}$$

$$h_L = 0.642\frac{V_2^2}{2g} + 0.497\,\frac{V_2^2}{2g} - \frac{V_2^2}{2g} = 0.139\,\frac{V_2^2}{2g}$$

Application of the same principles to the 2-way Y with all the water flowing through one branch resulted in a head loss equation of

$$h_L = 0.126 \frac{\overline{V}_2^2}{2g}.$$

As a result of the pressure investigation, it was concluded that the 2-way Y with 5°48' 13" converging passages would operate satisfactorily for all flow conditions with the high capacity slide gates. The recommended tunnel outlet piping system, therefore, consisted of a 3-way Y from the 26-foot diameter tunnel to the two 16-foot and one 13-foot diameter branches, two 2-way Y's from the 16-foot diameter pipes to the 9.5-foot diameter branches with slide gates at the ends, and one 2-way Y from the 13-foot diameter pipe to the 8-foot diameter branches with 96-inch hollow-jet valves at the ends (Figure 14).

The high capacity slide gates on the 9.5-foot diameter branches require the 2-way Y with the 5°48'13" converging passages to prevent cavitation pressures in critical areas. The hollow-jet valve on the 8-foot diameter branches create sufficient back pressure to permit the use of 2-way Y's with constant diameter passages.

Capacity of outlet tunnel piping system. To determine the losses in the overall piping system, the 1:61.82 scale model (Figure 15A) was attached to the laboratory supply system by using 8 feet of 5.05-inch inside-diameter plastic pipe, a 1.5-foot long 5.05- to 6-inch transition, 15 feet of 6-inch inside-diameter brass pipe, and a bellmouthed entrance to a 36-inch diameter pressure tank. The pressure tank was used to provide a greater range of head and discharge than could be obtained with the head box of the complete model. The pressure head upstream of the piping system was obtained from four piezometers located 90° apart in a ring in the 5.05-inch ID plastic pipe. The discharge was obtained from a Venturi meter.

The model gates on the ends of the branch lines were not exactly alike, and this necessitated an adjustment of gate opening to produce the 0.92 discharge coefficient of the Palisades gates. The model hollow-jet valves, because of their small size, could not be accurately set to produce flow conditions representing those of the prototype valves, and these valves were represented by orifices with a 0.70 coefficient of discharge.

The 2-way Y's with constant diameter passages were retained throughout on the 1:61.82 model since they were not to be studied individually, and because the difference in losses between these Y's and the converging ones would be negligible in respect to the losses for the overall system.

A discharge coefficient related to the loss of head of the piping system was obtained with the model gates and valves fully opened.

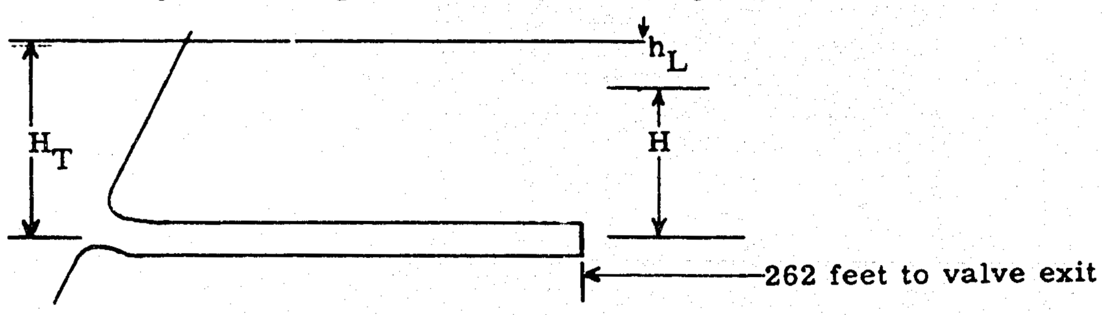
The coefficient was obtained from the equation $C = \dfrac{Q}{A\sqrt{2gH}}$

where
- Q = discharge in 26-foot tunnel, cubic feet per second
- A = area of 26-foot tunnel, square feet
- H = total head, pressure plus velocity head in the tunnel 262 feet upstream of the valve exits, feet
- C = coefficient obtained from model experiments

The pressure head $\frac{P}{\gamma}$ was measured at the piezometer ring and the velocity head $\frac{\overline{V}^2}{2g}$ was computed for the measured discharges to obtain the total head in the model piping system. From the total head and the discharge, the coefficient, C, was found to be 0.57. This coefficient of 0.57 is probably slightly lower than in the prototype because of the higher relative losses of the 1:61.82 scale model. It applies only to a discharge with the four slide gates and two hollow-jet valves fully opened.

By computing the losses, h_L, (entrance, friction, etc.) in terms of the velocity head in the 26-foot conduit, and knowing the head available from the reservoir, the velocity in the 26-foot pipe and the discharge of the outlet works may be obtained.

This may be accomplished in the following manner:



$$H_T = h_L + H$$

$$Q = CA\sqrt{2gH}$$

$$H = \frac{Q^2}{A^2 2gC^2} = \frac{\overline{V}^2}{2gC^2}$$

$$H_T = h_L + \frac{\overline{V}^2}{2gC^2}$$

where C = 0.57

H_T = reservoir head to conduit ℄

h_L = head lost in the tunnel

H = total head available to the centerline of the pipe 262 feet upstream of valve and gate exits (piezometer location in model)

The distribution of discharge from the individual outlet branches was obtained during the coefficient tests by a volumetric measurement of the discharge. The two hollow-jet valves discharged 22.6 percent of the total flow and the slide gates 77.4 percent. There was no apparent difference in the quantity of water discharged from each gate.

Capacity of power tunnel piping system. The capacity of the two outlets from the power tunnel was determined by the procedure used for the outlet piping system. The power tunnel outlet section of the 1:61.82 scale model was attached to the pipe from the 36-inch diameter pressure tank and measurements were made of the total head in the tunnel 203 feet upstream from the gate exits, and of the discharge from the gates. Both slide gates were set for a coefficient of 0.92 to correspond to a fully-opened prototype gate. The coefficient of discharge for the two gates with respect to the tunnel was C = 0.24.

A weight measurement with respect to time of the discharge from each gate indicated that the discharge was divided approximately equally between the two gates. The coefficient of discharge for a single gate set to represent the full open condition, based on the tunnel area, was 0.12. The discharge capacity of the power tunnel outlets was adequate.

Outlet Works Stilling Basin

Operation of preliminary design basin. The wall which divided the outlet stilling basin into two sections 104 and 54 feet wide and served to separate the outlet tunnel and power tunnel flow during the diversion period, separated the flow of the two penstock gates from that of the five outlet gates, to make essentially separate stilling basins. This arrangement was desirable because all normal releases were to be made from the gates of the outlet tunnel, while the gates from the power penstock were to be operated only when the powerplant was inoperable. No chute or floor blocks were provided in this preliminary stilling basin design to aid in forming the hydraulic jump, but a 5-foot high, 2:1 sloping sill was provided at the end of the basin.

Operation of the five outlet gates and the two power tunnel gates at equal openings resulted in uniform and satisfactory hydraulic jumps in the basin sections. However, unsymmetrical valve combinations produced unsatisfactory jump conditons. Tests to improve the basin performance were made after the piping was changed to include the two hollow-jet valves in place of the center slide gate of the outlet tunnel.

Stilling basin sweep out tests. At a discharge of 28,500 cfs through the outlet tunnel basin, the tail-water level could be lowered 4 feet below the 5380.9 elevation given by the preliminary tail-water curve (Figure 31) before the jump would sweep from a point on the chute to the intersection of the chute and basin floor. It was believed that better performance could be obtained at even lower tail-water elevations by adding chute blocks and possibly floor blocks to the basin. Tests were made to determine the effectiveness of such blocks.

Chute floor pressures. Because the model tests made to study the spreading of the gate jets showed that the 15-foot long horizontal section of the floor immediately downstream of the gates was not essential for satisfactory stilling basin performance, it was removed and the basin shortened 15 feet. Pressures taken on this shorter chute showed a maximum subatmospheric pressure of 2.8 feet of water at a discharge of 31,000 cfs. This pressure occurred at Station 19+45, 45 feet downstream of the gate frame exit and on the centerline of the basin. This pressure was not low enough to produce cavitation so the chute profile was considered satisfactory.

Operation with recommended gate and valve arrangement. The gates of the preliminary outlet works piping system were to be equally opened and the stilling basin was satisfactory where there was approximately equal flow per foot of width. In the case of the recommended piping system the gates and valves would not be equally open for much of the total operation. It was planned that two hollow-jet valves would be used for regulating the flow up to the point where the valves were fully opened. If greater discharges were to be passed the flow would be transferred to one of the slide gates, which would be opened fully, and the valves would be throttled to release the proper additional rate of flow. If the valves again reached their capacity, a second slide gate would be opened. If necessary, this would be repeated until all four slide gates and both hollow-jet valves were open. This operation would impose severe conditions of energy concentration and flow distribution in the basin. Studies were therefore made to determine the adequacy of the basin.

The dividing wall between the outlet and power tunnel basin was removed to determine the need of the wall. The jump in the stilling basin was deflected to the left by an eddy that formed at the right side of the basin (Figure 17A). This action prevented effective use of the full stilling basin width. The wall was replaced and the top elevation was set at 5378.5 instead of 5390.0.

With all gates and valves operating at equal openings, the basin performance was acceptable. With symmetrical operation of only part of the gates and valves, the performance was not acceptable because eddies formed and deflected the jump, and the energy dissipation was poor, (Figures 17B and F). Unsymmetrical operation of the gates and valves increased the intensity of the eddies and produced waves that carried out into the river channel (Figure 17C, D and E). The eddies would be powerful enough to sweep gravel and boulders into the basin and cause abrasive erosion on the concrete walls and floor. The flow through the preliminary basin with the single dividing wall was, therefore, considered unsatisfactory. Observation of the basin resulted in a scheme to use additional dividing walls to separate the discharges of pairs of gates and valves.

Recommended stilling basin. The outlet tunnel stilling basin was separated into three sections by two dividing walls on the chute (Figure 18). The elevation of the top of the main dividing wall downstream from Station 19+38.25, and of the two intermediate walls, was set at 5378.5. To reduce the cost of the walls, the downstream ends were sloped to elevation 5355.0 (10 feet above the basin floor). Chute and floor blocks were provided in the stilling basin to increase its effectiveness in dissipating energy. The chute blocks, 6.75 feet high and 5 feet wide, were located at the junction of the chute and floor of the stilling basin. The upstream ends of the 8-foot high by 5-foot wide streamlined floor blocks were located 69.5 feet downstream of the chute blocks.

Each section of the divided chute tended to act as a separate stilling basin for a pair of gates or valves, and the eddy that formed in the downstream end of the basin was reduced in size and intensity, and confined to the region near the exit of the basin (Figure 19). The individual sections were large enough to handle the discharge from pairs of gates or valves and also small enough to form a good jump with the discharge from only one gate or valve.

The performance of the divided basin was satisfactory with effective energy dissipation for all combinations of gates and valves. Water splashed over the walls between adjacent sections, but only in relatively small quantities.

Stilling basin sweep out. The revised tail-water curve, based upon there being material removed from a borrow area in the river bank, is shown in Figure 31. When the tail water was lowered 4 feet below the computed normal elevation of 5380.3, with a discharge of 30,550 cfs from the equally opened outlet gates and valves, the front of the jump moved from a point over the chute blocks to the upstream end of the floor blocks. Similarly, when the tail water was lowered 6.5 feet from the normal elevation with a combined discharge of 46,100 cfs from the outlet and power tunnel gates, the front of the jump moved from the chute blocks to the floor blocks. At the normal tail-water elevation, the front of the jump moved up and downstream about 15 feet. This movement did not occur simultaneously in each section of the chute but momentarily exposed the chute blocks in a random manner. The movement was especially apparent for smaller discharges and lower tail-water elevations when both gates of a pair were operating in their section of the basin. In general, the computed normal tail-water depth provided an adequate margin of safety to prevent sweep out.

Erosion of stilling basin exit channel--maximum flow. The effectiveness of the outlet and penstock stilling basins with the dividing walls, chute blocks, and floor blocks was checked by erosion tests of the exit channel. The riverbed contours downstream of the outlet works, spillway, and powerplant were formed in sand. Five-eighths inch gravel was placed downstream of the basin exit to represent 3 feet of dumped riprap to protect the riverbed from erosion (Figures 2 and 20A).

The grid of string in Figure 20A at 5-foot intervals, representing approximately 300 feet prototype, was used to locate exit channel contours and the riprap.

Operation of the combined outlet tunnel and power tunnel stilling basin for 4 hours at a discharge representing 46,100 cfs and a tailwater elevation of 5382.1 resulted in practically no erosion (Figures 20A and B). An eddy that formed between the basin discharge and the river bank, and rotated in a clockwise direction, was of low velocity and did not appear to affect the powerplant tail water. A small amount of sand was deposited downstream of the end of the right training wall along the boundary of the eddy and the outlet works flow. This sand had been washed from beneath the riprap and carried downstream by the water for a distance equal to approximately two-thirds the length of the riprap. A slight decrease in the riverbed elevation occurred immediately downstream of the end of the riprap. The material from this area moved downstream and formed a low sand bar which did not impede the flow. The extent and depth of riprap was believed sufficient and the exit channel protection was considered satisfactory for the maximum combined discharge of the outlet and the power tunnels.

Erosion of stilling basin exit channel-gate and valve combinations. Additional erosion tests were made for various combinations of the gates and valves. Operation of the outlet basin at a discharge of 31,600 cfs with normal tail water 5380.4 produced only slight erosion of the riverbed and formed a low sand bar downstream of the riprap (Figures 20C and D). The exit channel protection was satisfactory for outlet works operation at maximum discharge.

Erosion resulting from the operation of two slide gates and two hollow-jet valves at the left of the basin was essentially the same as for the two slide gates alone. For both operating conditions, the jet tended to flow close to the left training wall and to diverge at the exit of the basin (Figure 21A). Erosion downstream of the riprap caused a slight reduction in the exit channel elevation and formed a low sand bar downstream and to the right. The lowest elevation was 5362, 8 feet below riprap elevation 5370 (Figure 21B). Erosion depth was greater than that which occurred for maximum discharge and was attributed to a correspondingly lower tail-water depth and a more concentrated flow of water from the stilling basin exit. The exit channel protection was considered adequate.

The deepest erosion resulted from the power tunnel gates operating for 3 hours (model) at a discharge representing 14,700 cfs (Figure 21C). Erosion to a depth of 12 feet below elevation 5370 occurred downstream of the riprap (Figure 21D). Although the scour downstream of the riprap was quite severe, the protection of the riverbed was considered adequate.

The outlet works erosion tests indicated that the stilling basin and the riverbed protection were satisfactory for all operating combinations of the outlet valves and gates.

The Spillway

Preliminary Spillway

Operation of the preliminary 26-foot diameter tunnel spillway. When the model of the preliminary spillway was placed in operation the entrance flow conditions were found to be satisfactory, but three other problems were encountered: (1) the capacity of the 26-foot diameter tunnel was smaller than that required for the design discharge of 48,000 cfs, (2) the center pier separating the radial gates needed lengthening and streamlining, and (3) the abrupt transition from the tunnel to the exit channel lining caused the water to overtop the lining (Figure 22).

At a discharge of 43,000 cfs, the tunnel exit and then the entire tunnel and its entrance transition filled to submerge the overflow section and to limit the capacity of the spillway to 46,800 cfs at the maximum reservoir elevation of 5621.0. Operation of the spillway in a submerged condition is shown on Figure 22C. The restricted capacity of 46,800 cfs was not much less than the desired capacity of 48,400 cfs, but the tunnel was not intended to operate under pressure, and studies were subsequently made on a tunnel of larger diameter to increase the capacity such that the tunnel flow would have a free water surface.

Water entered the tunnel spillway in a tranquil manner throughout the range of discharge. Some turbulence occurred as the water flowed past the slope on the left-hand side of the approach channel. This turbulence passed through the overflow section without apparent effect on the capacity. Water entered from the right side around the 40-foot radius end pier with only slight turbulence. For discharges to approximately 30,000 cfs a ridge of water with a width of approximately 10 percent of the tunnel diameter formed in the horizontal tunnel immediately downstream of the vertical bend. The ridge first was formed when the flow from the two bays of the overflow section joined in the inclined tunnel a short distance downstream of the center pier. This ridge, or fin, was not evident in the vertical bend but appeared downstream of the bend in the horizontal tunnel. The fin was not wide enough to close the tunnel, but was high enough to reach the crown of the 26-foot diameter tunnel. A reshaping of the downstream end of the pier was indicated but the tests were deferred until the model tunnel could be enlarged.

Water leaving the tunnel overtopped the exit channel lining in the preliminary design because the transition from the circular tunnel to the trapezoidal channel was abrupt (Figures 22B and D). Water flowed from the tunnel and spread horizontally to impinge on the exit channel walls and then overtop the walls. This action was unsatisfactory.

Modified Tunnel Spillway (Recommended Design)

Elliptical-shaped spillway entrance piers. An economy was affected in the design of the spillway entrance approach by revising the shape of the right and left entrance piers. The amount of vertical wall required for the 40-foot radius of the preliminary piers was costly and field exploration showed that it would be difficult and expensive to provide suitable support for the right-hand wall. Both walls were revised from the preliminary 40-foot radius curve to the elliptical curve

$\frac{X^2}{(30)^2} + \frac{Y^2}{(12.5)^2} = 1$, with the right wall being completed with a 7-foot 6-inch radius around the outside of the pier (Figure 23). The width of the right pier was reduced from 80 feet to 20 feet with a corresponding reduction in wall length and in foundation requirement. The elliptical curve of the left pier continued until it intercepted a tangent at right angles to the spillway centerline and this tangent was extended into the hillside.

The flow conditions in the modified spillway entrance were satisfactory, although there was a slight increase in the turbulence of flow (Figure 24A). The flow contraction along the right pier increased with discharge and formed a standing wave within the inlet structure. The flow contraction along the left pier was less pronounced and no standing wave appeared. The waves at the entrance to the tunnel were dissipated rapidly as the flow accelerated in the shaft. No unsatisfactory flow conditions resulted from the use of the elliptical entrance piers, and they were considered satisfactory.

Center pier lengthened at downstream end. An increase in the length of the center pier at the downstream end served two purposes. The modified 120-foot long pier (Figure 25) extended 40 feet farther into the inclined shaft to add support to the tunnel transition, and to reduce the height of the fin that formed downstream of the pier end. The fin of water in the tunnel at the downstream end of the pier where the flow from the two gates met was reduced in size by tapering the last 60 feet of the pier from a thickness of 6 feet to 3 feet, or 1 foot less than the preliminary design. In addition, the pier directed the flow of water over a greater distance in the inclined shaft and as the flow accelerated, the sideward spreading of the flow was reduced. The flow conditions in the shaft and tunnel were acceptable and the extended pier was considered satisfactory.

Tunnel enlarged to 28 feet in diameter. To increase the spillway capacity and to provide a free water surface in the tunnel, the tunnel diameter was enlarged from 26 feet to 28 feet. This entailed a change of the tunnel transition and the lower vertical bend because the preliminary transition section and upper bend decreased in diameter from 34 to 26 feet; whereas, the modified transition and bend decreased from 34 to 28 feet (Figure 26). The elevation of the invert of the junction of the lower bend and tunnel at 5402.0 and of the tunnel exit at

5370.0 were the same as the preliminary design. The slope of the tunnel was approximately 0.019 in both the preliminary and modified tunnels.

Operation of the spillway with the elliptical entrance piers, the longer center pier, and the 28-foot diameter tunnel disclosed satisfactory operation and that the tunnel would flow with a free water surface at maximum reservoir elevation of 5621.0, and with the desired maximum discharge of 48,400 cfs (Figure 24).

The average water surface profile along the sides of the tunnel inlet transition and shaft indicated a rather uniform acceleration of the flow from the crest to the bend (Figure 24B). The centerline depth was generally lower than the depth at either side. A fin of water occurred in the horizontal tunnel downstream of the lower bend. With the discharge increased above 15,000 cfs the fin decreased and disappeared. Flow conditions were satisfactory in the inclined shaft.

The water surface through the tunnel had no undue waves or fluctuations downstream of the bend. Surface waves of a small choppy nature which were attributed to wall disturbance and turbulence from the inclined shaft appeared throughout the tunnel. The wave amplitude remained essentially constant for all discharges.

The tunnel operated with a free water surface to a maximum of 48,400 cfs at a reservoir elevation 5621.0. The water surface touched the top of the tunnel at maximum discharge in the area of Station 22+66, 180 feet upstream of the tunnel exit. When the flow was slightly restricted at the tunnel exit, the tunnel would flow full from the exit to the tunnel bend. When the restriction was removed, the tunnel returned to free surface flow. An increase in tail-water elevation to 5400.0, 14 feet above normal for the maximum design discharge, did not affect the flow in the exit channel and tunnel. Operation of the tunnel spillway with a single gate open was satisfactory (Figure 27). The flow of water up the wall just downstream from the lower critical bend (Figure 27B) did not close the tunnel or produce appreciable disturbance in the exit channel.

Modified spillway tunnel exit transition. The transition from the tunnel exit to the downstream channel was modified to prevent overtopping of the channel lining and to provide smooth flow from the circular tunnel to the trapezoidal channel (Figure 28). From Station 24+00.00 to the exit portal at Station 24+46.35, the lower one-half of the 28-foot diameter tunnel was gradually changed from a circular section to a rectangular section 28 feet wide. A warped transition 73.65 feet long changing from vertical walls to 1/2 to 1 sloped walls connected the tunnel exit to the channel lining. An upward curve was added at the channel exit floor to deflect the water upward to protect the exposed foundation rock from heavy washing. This curve was 20 feet long with a radius of 64 feet 10 inches, and increased the floor height from elevation 5370.0 to elevation 5373.0.

Water flowed through the transition in a satisfactory manner without overtopping the walls at any discharge (Figure 24C). Flow conditions over the deflector at the channel exit were satisfactory with the water flowing upward and travelling a considerable distance before falling back to the river surface.

Another design change was tried in which the slope of the tunnel was increased by lowering the exit channel from elevation 5370.0 to 5360.0. The tunnel flowed freely to an overload discharge of 50,000 cfs with a reservoir elevation of 5622.0, but freeboard above the tunnel water surface was very limited and a prototype tunnel resistance greater than that represented by the model might cause the tunnel to run full at flows near the maximum. The channel floor was returned to elevation 5370.0 to reduce water pondage within it to a minimum, thus offering greater protection against winter ice formation.

Erosion of downstream riverbed. The excavated exit channels of the powerplant, outlet works, and spillway were represented in the model with sand, with a protective layer of gravel riprap, according to the general plan of Figure 2. The model was operated 4 hours with a discharge representing 46,100 cfs from the outlet works and a discharge of 48,400 cfs from the spillway (Figure 29). This total discharge was used because the outlet works will reach maximum capacity and then the spillway will be operated. Water flowed from right to left just downstream of the outlet works stilling basin and toward the flow from the spillway channel. This general flow was a part of a large eddy rotating about a center located some distance downstream of the powerplant. Water from the spillway channel was deflected slightly to the left, but in general, flowed on the spillway centerline. Flow conditions in the river channel appeared good with no undue surface roughness, but a 70-foot deep hole that extended approximately 600 feet was eroded downstream of the spillway channel exit (Figure 30). In addition, the left bank was eroded and the walls and the assumed foundation rock at the downstream end of the spillway exit channel were exposed. No damage to the wall would result unless the rock foundation and the wall were extensively undermined. This may be a possibility in case there are continued high discharges. Protection of the rock and channel will be afforded by the upward curve in the floor of the channel exit, but the extent of the protection could not be evaluated in the model.

The riverbed was scoured to elevation 5341 just downstream of the riprap protection of the outlet works channel. This depression joined with the one caused by the spillway. The junction of the eroded areas coincided with the entrance of the flow from the eddy downstream of the basin with that of the spillway flow (Figure 29). It was concluded that the spillway would cause considerable erosion in the riverbed, but that with proper maintenance of the channel, the discharge could be passed successfully.

Spillway capacity. The discharge capacity curves of Figure 31 are for the recommended spillway using the elliptical entrance piers, the lengthened center pier, and the 28-foot diameter tunnel. The plot includes capacity curves for the radial gates at various openings, and the tail-water curve used in concluding phases of the model study. The capacity of the spillway at the maximum reservoir elevation of 5621.0 was 48,400 cfs.

FIGURE 1
REPORT HYD. 350

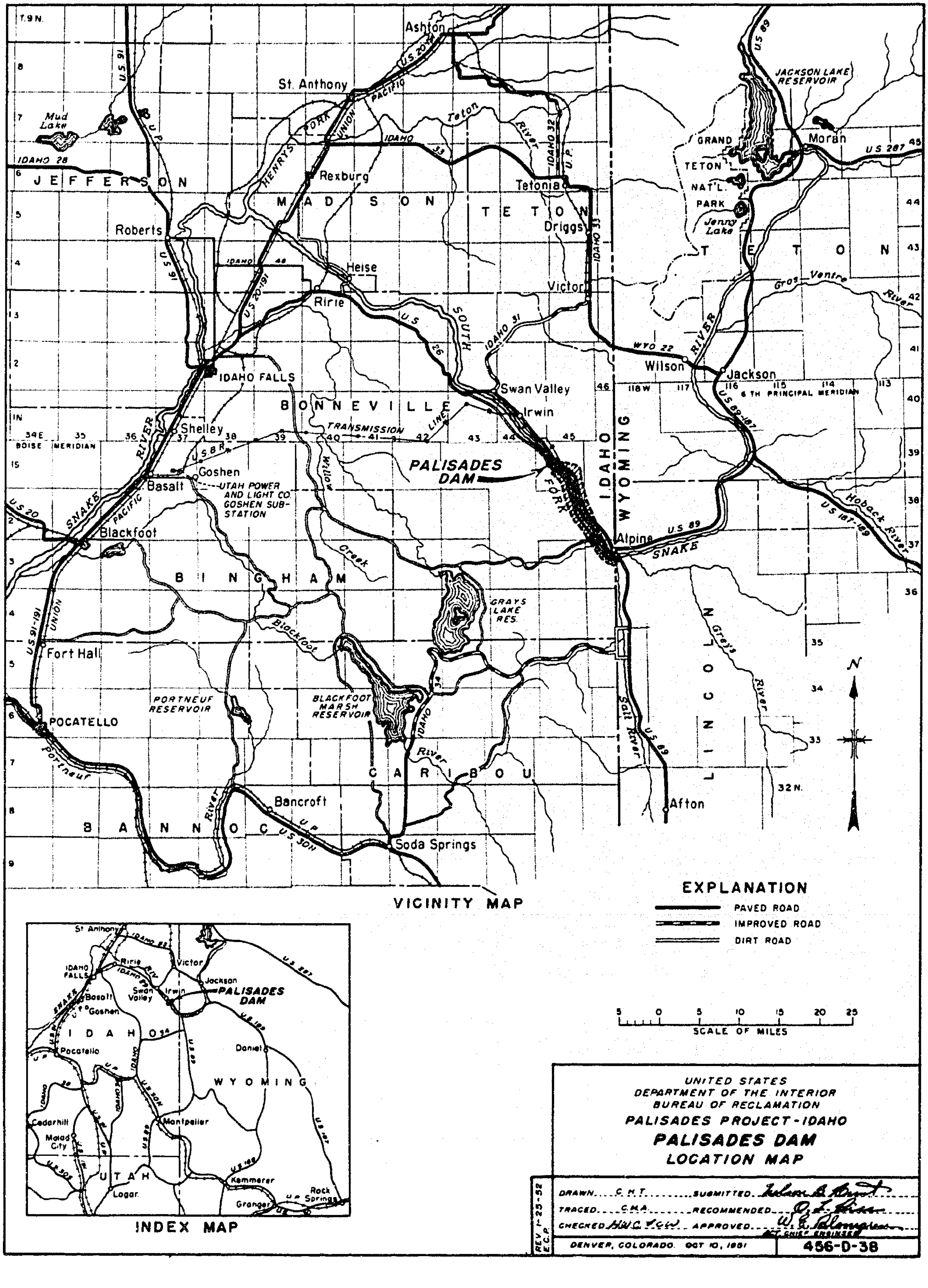
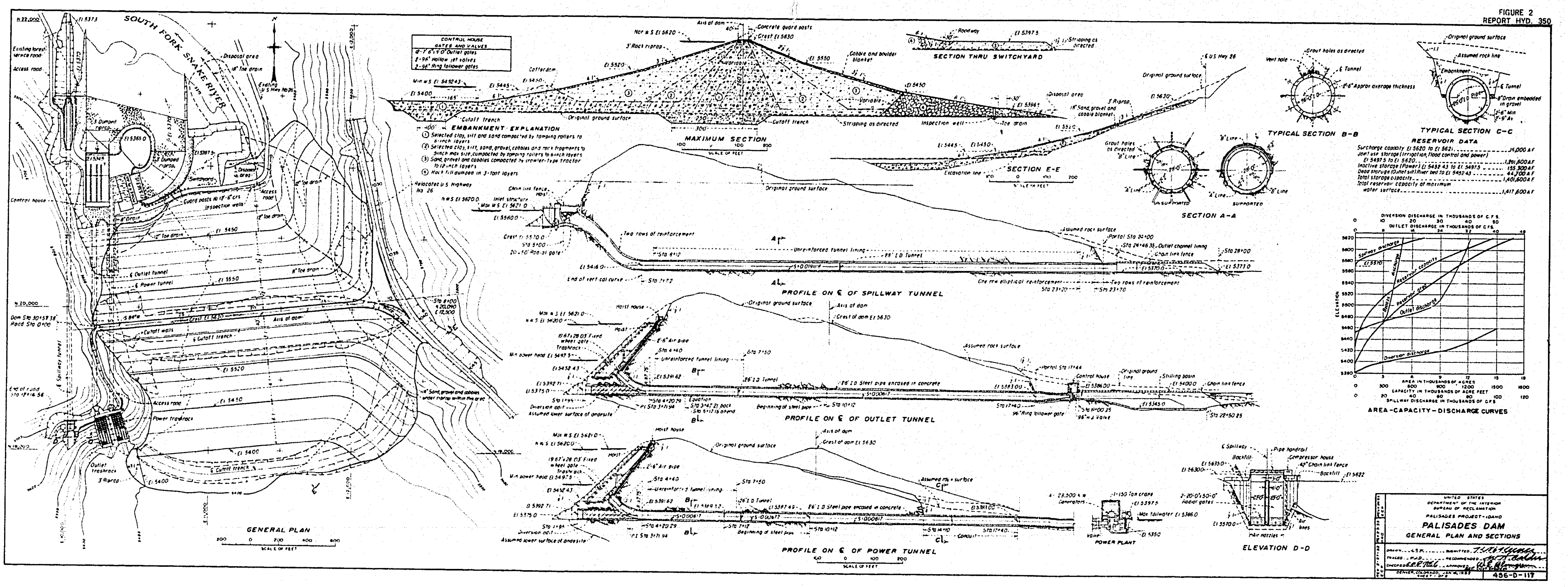
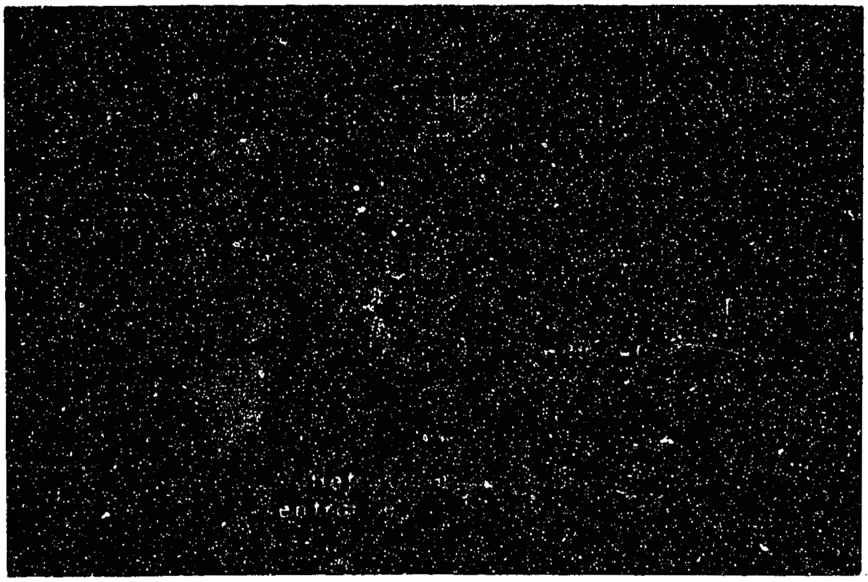
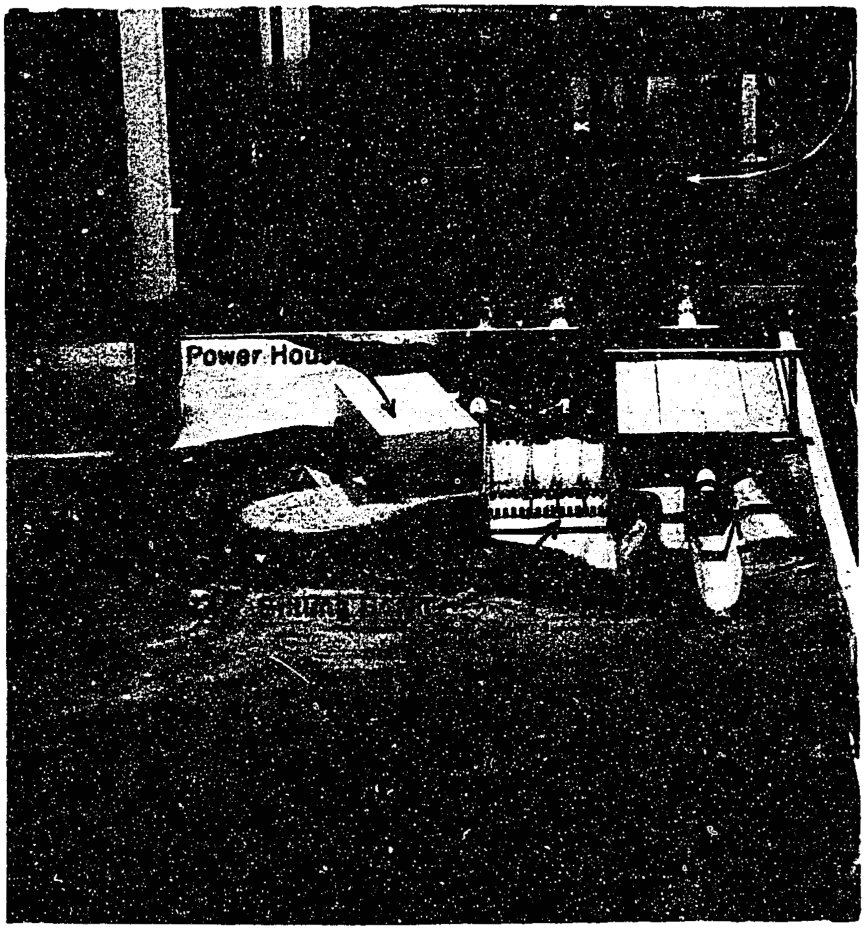


FIGURE 2
REPORT HYD. 350



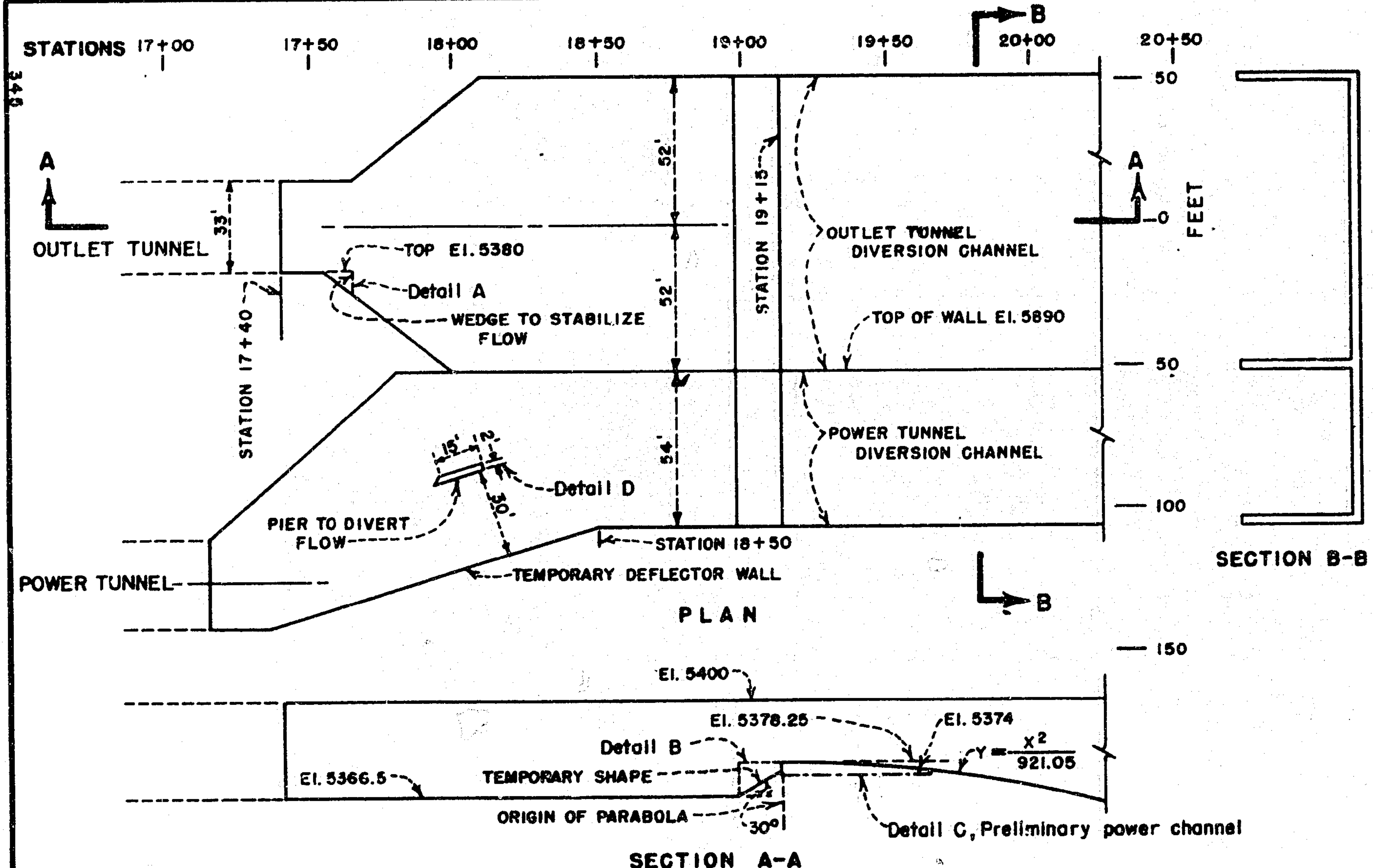


A. Spillway and tunnel entrances in model head box



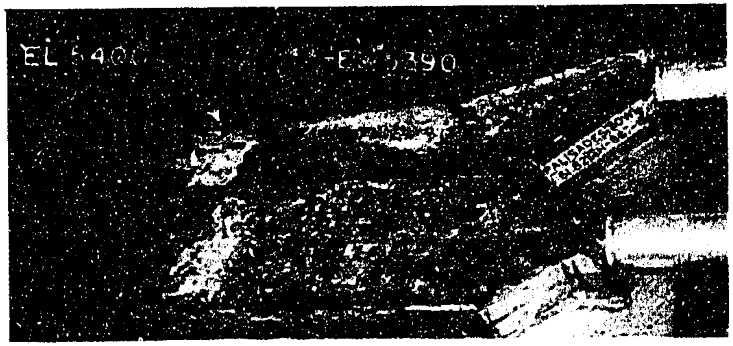
B. Outlet works stilling basins, and spillway channel in model tailbox - Bank protection representing 3-foot dumped riprap and grid system representing 300-foot squares

PALISADES DAM
1:61.82 scale model

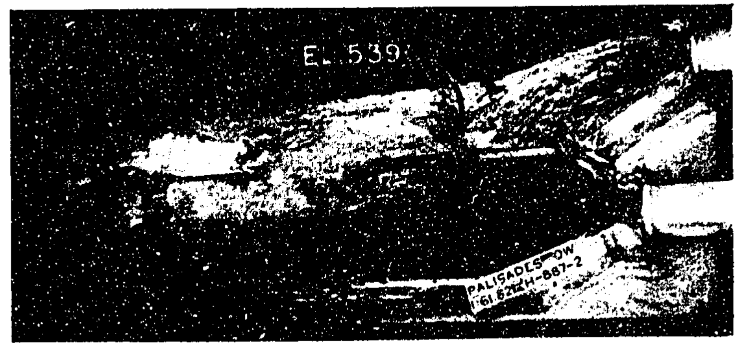


PALISADES DAM
PRELIMINARY DIVERSION CHANNEL DETAILS

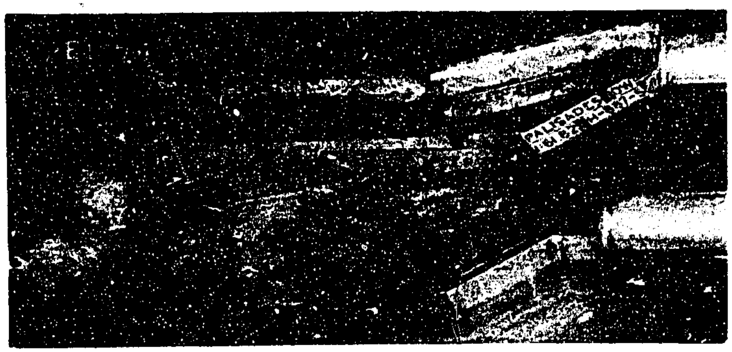
FIGURE 4
REPORT HYD. 350



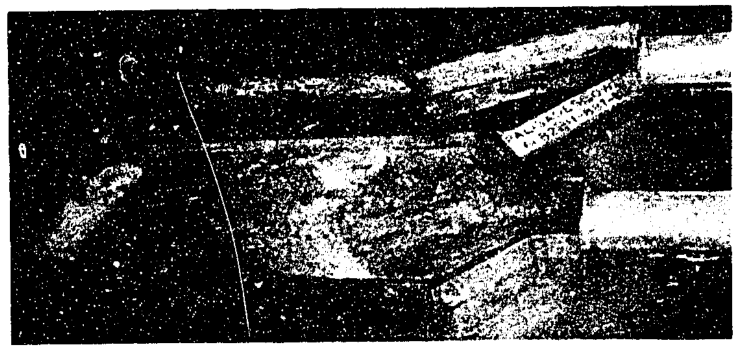
A. Preliminary outlet and power tunnel channels - Discharge 18,500 cfs per channel



B. Power tunnel diversion channel - Discharge 33,000 cfs



C. Outlet tunnel diversion - Symmetrical flow through center of channel - Discharge 25,500 cfs



D. Outlet tunnel flow deflected to left side of channel by eddy on right side - Discharge representing 25,500 cfs

E. Outlet tunnel flow deflected to right side of channel by eddy on left side - Discharge 25,500 cfs

PALISADES DAM

FLOW CONDITIONS IN PRELIMINARY OUTLET AND POWER TUNNEL DIVERSION CHANNELS
1:61.82 Scale Model

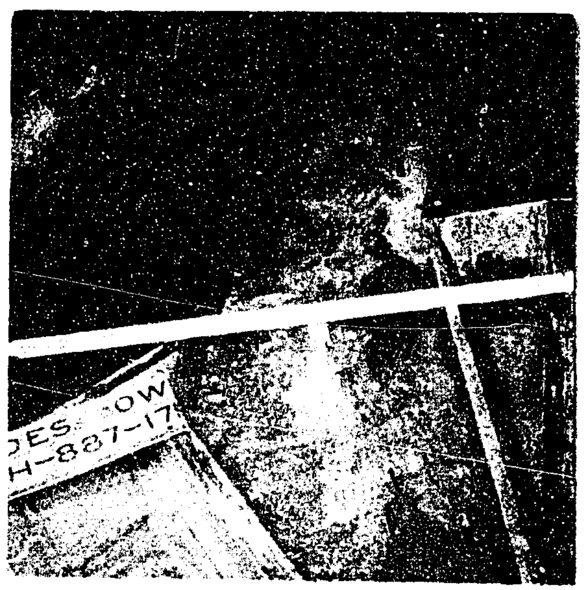
Figure 5
Report Hyd-350

Figure 6
Report Hyd-350

A. Preliminary channel with chute floor elevation 5374 - Discharge 26,000 cfs

B. Floor elevation 5378.25 with profile same as outlet channel - Discharge 27,700 cfs

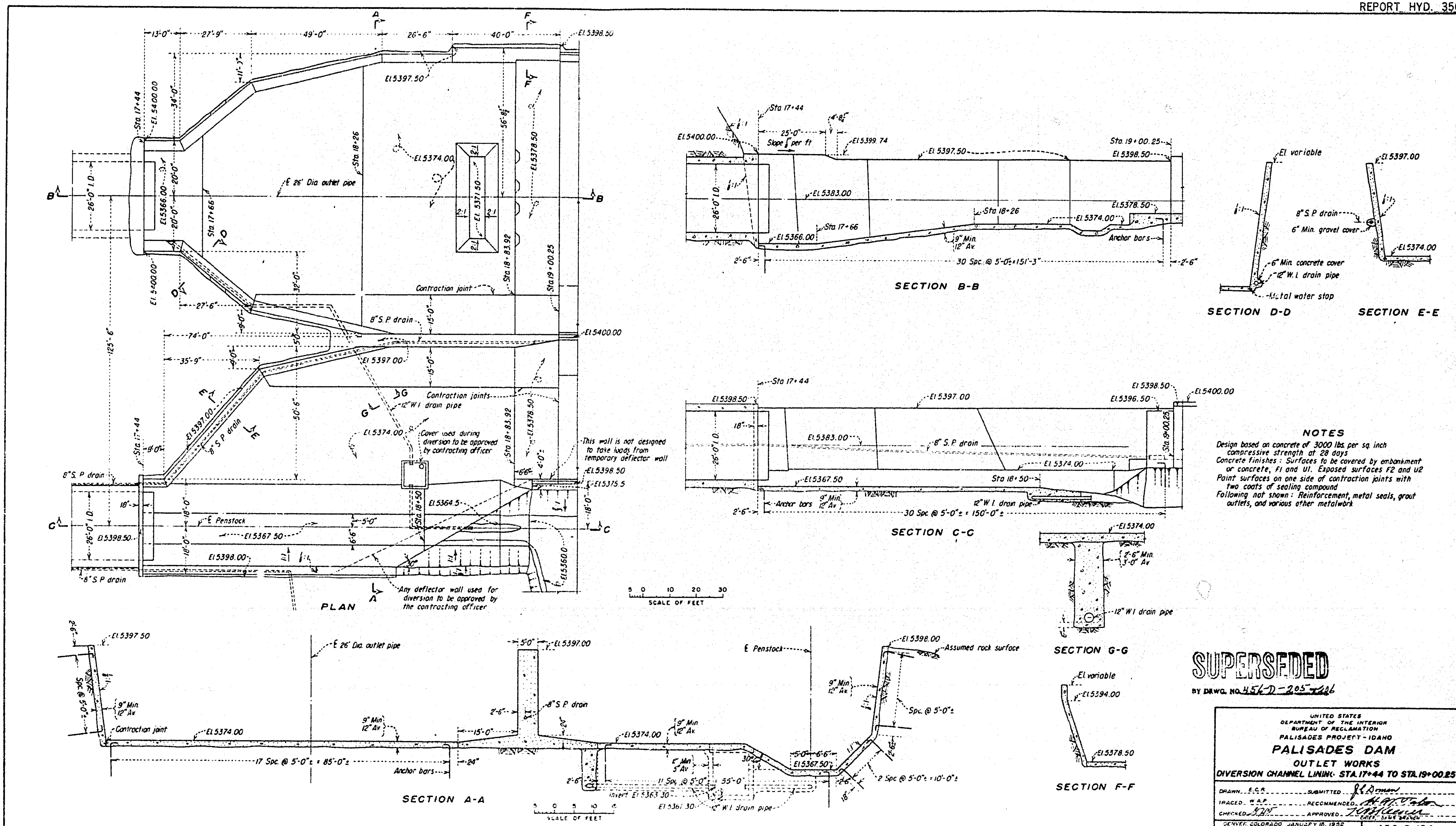
C. Channel with preliminary floor elevation 5374 and long deflector wall - Discharge 26,000 cfs

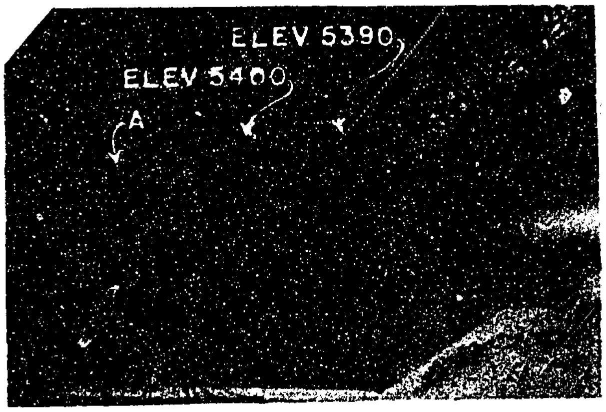


D. Channel as C but deflector pier added to prevent overtopping - Discharge 32,000 cfs

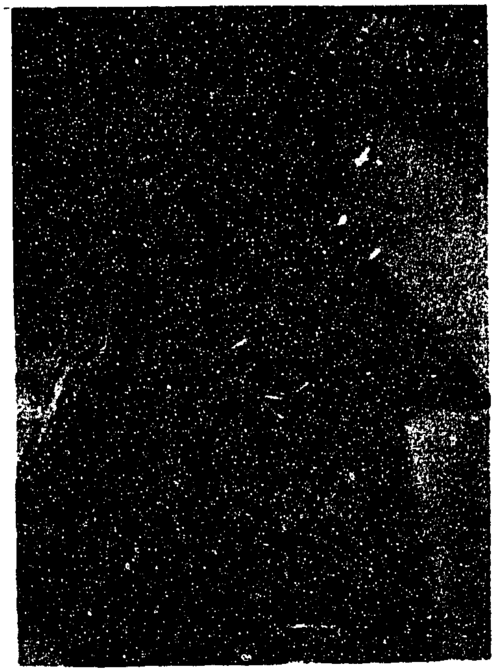
PALISADES DAM

FLOW CONDITIONS IN PRELIMINARY POWER TUNNEL DIVERSION CHANNEL
1:61.82 scale model


PLAN
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SCALE OF FEET
℄ 26' Dia outlet pipe
℄ Penstock
Contraction joint
Contraction joints
8" S.P. drain
12" W.I. drain pipe
Cover used during diversion to be approved by contracting officer
This wall is not designed to take loads from temporary deflector wall
Any deflector wall used for diversion to be approved by the contracting officer
Assumed rock surface
Anchor bars
Metal water stop
6" Min. concrete cover
6" Min. gravel cover
El. variable
NOTES
Design based on concrete of 3000 lbs. per sq. inch compressive strength at 28 days
Concrete finishes: Surfaces to be covered by embankment or concrete, F1 and U1. Exposed surfaces F2 and U2
Paint surfaces on one side of contraction joints with two coats of sealing compound
Following not shown: Reinforcement, metal seals, grout outlets, and various other metalwork
SUPERSEDED
BY DRWG. NO. 456-D-205-226
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PALISADES PROJECT - IDAHO
PALISADES DAM
OUTLET WORKS
DIVERSION CHANNEL LINING STA. 17+44 TO STA. 19+00.25
DRAWN E.C.R.
TRACED W.A.P.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO, JANUARY 18, 1952
456-D-124

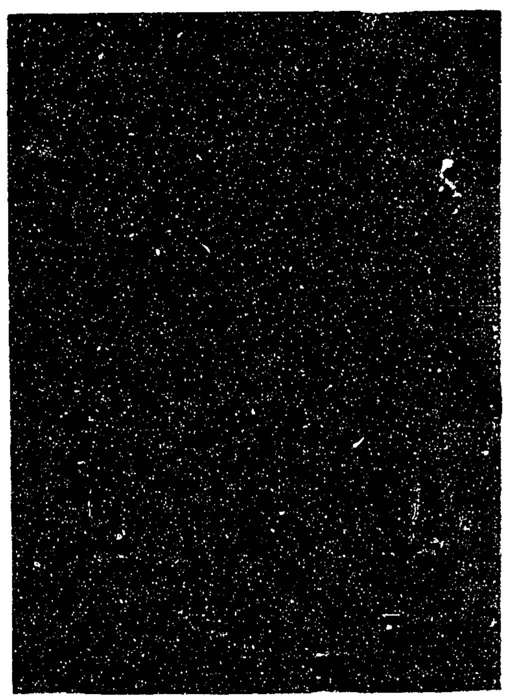


A. Outlet tunnel diversion - Discharge 26,000 cfs



B. Power tunnel diversion - Discharge 13,000 cfs

C. Power tunnel diversion - Discharge 18,000 cfs



D. Power tunnel diversion - Discharge 23,000 cfs

PALISADES DAM

FLOW CONDITIONS IN OUTLET DIVERSION CHANNEL AND IN POWER TUNNEL DIVERSION CHANNEL WITH DEFLECTOR WALL 1
1:61.82 scale model

Figure 9
Report Hyd-350

A. Discharge of 13,000 cfs

B. Discharge of 18,000 cfs

C. Discharge of 23,000 cfs

PALISADES DAM

FLOW CONDITIONS IN POWER TUNNEL DIVERSION CHANNEL
WITH DEFLECTOR WALL 2
1:61.82 scale model

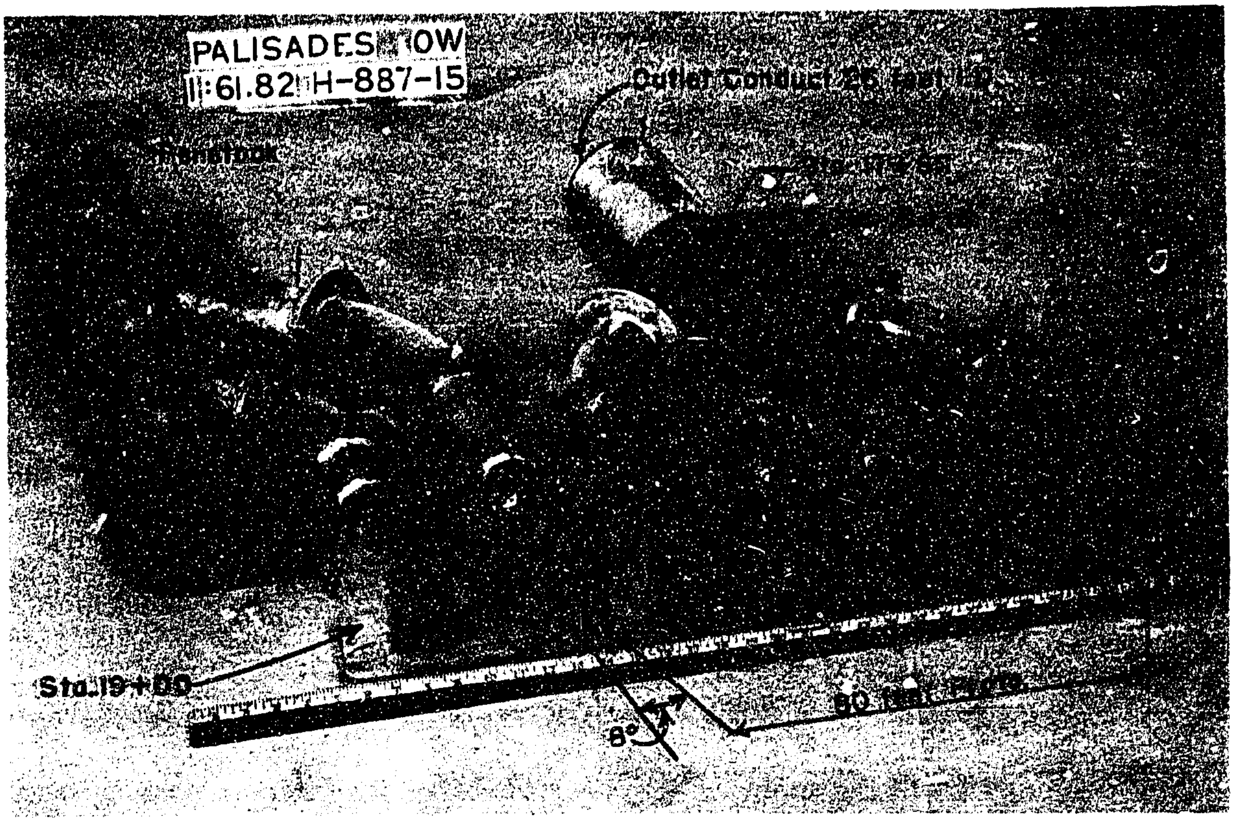
A. Discharge of 13,000 cfs

B. Discharge of 18,000 cfs

C. Discharge of 23,000 cfs

PALISADES DAM

FLOW CONDITIONS IN POWER TUNNEL DIVERSION CHANNEL
WITH DEFLECTOR WALL 3
1:61.82 scale model

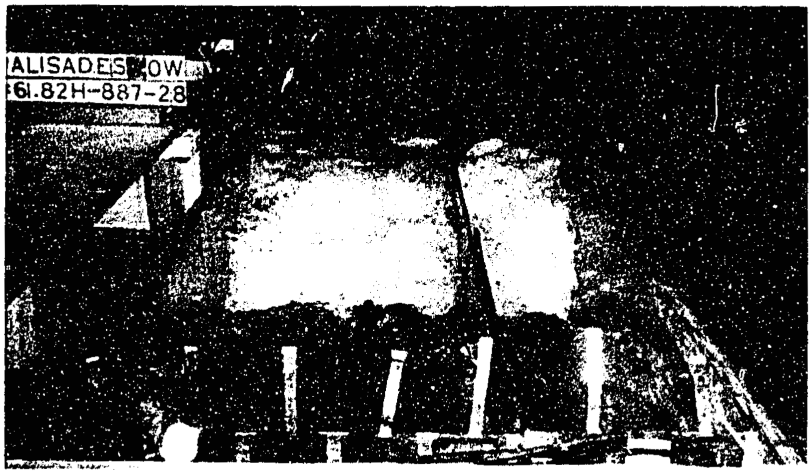


A. Preliminary piping system

B. Total discharge 50,000 cfs (33,000 cfs through outlet tunnel) - 8° divergence on gate frames - Tailwater elevation 5383.0

PALISADES DAM

PRELIMINARY OUTLET PIPING SYSTEM AND STILLING BASINS
1:61.82 scale model

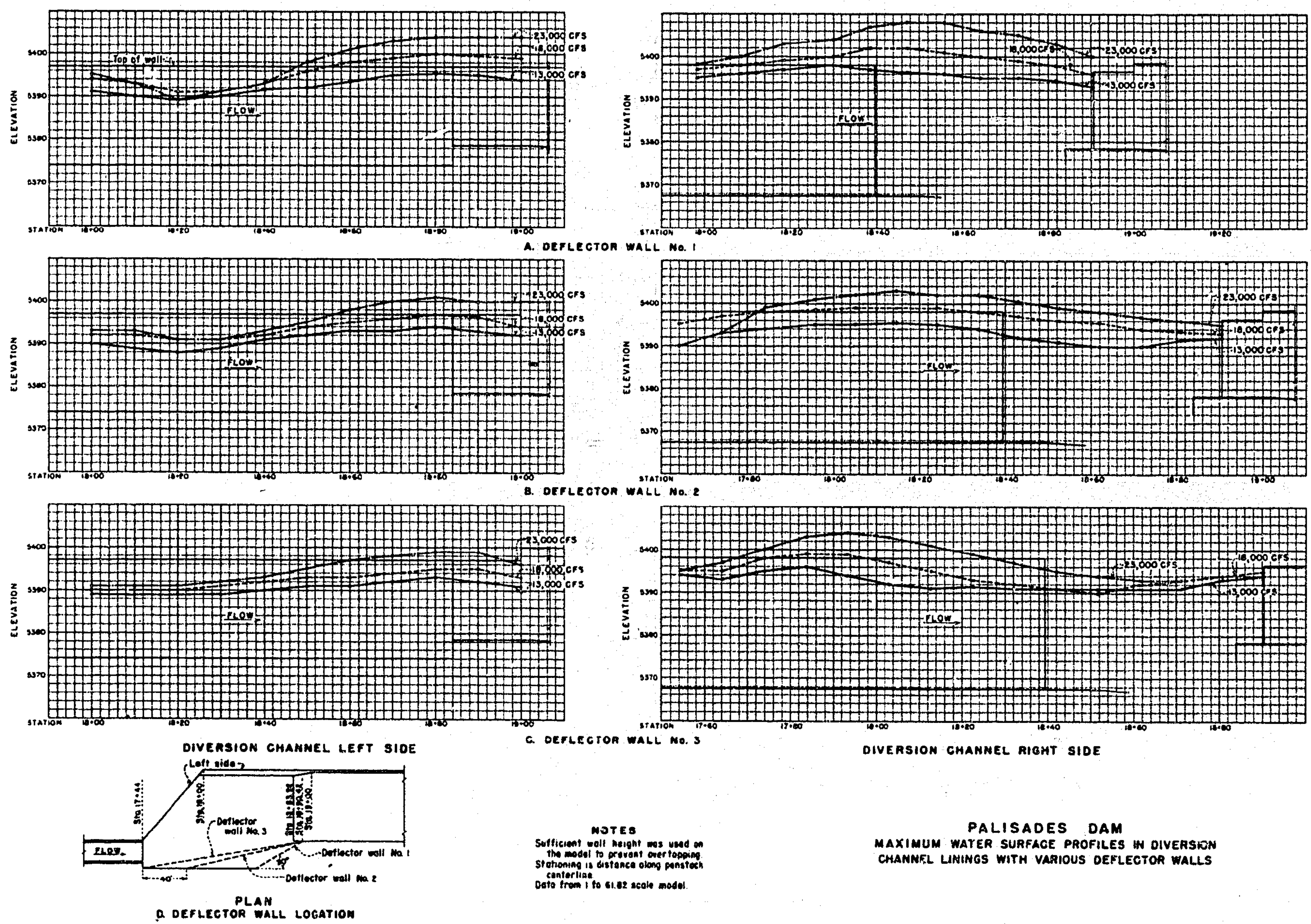


A. Total discharge 50,000 cfs (33,000 cfs through outlet tunnel) - 4° divergence on gate frames - Tailwater elevation 5383.0

B. Total discharge 50,000 cfs (33,000 cfs through outlet tunnel) - Parallel walls on gate frames - Tailwater elevation 5383.0

PALISADES DAM

EFFECT OF DIVERGENCE OF GATE FRAME WALLS ON FLOW IN PRELIMINARY STILLING BASIN CHUTE
1:61.82 scale model



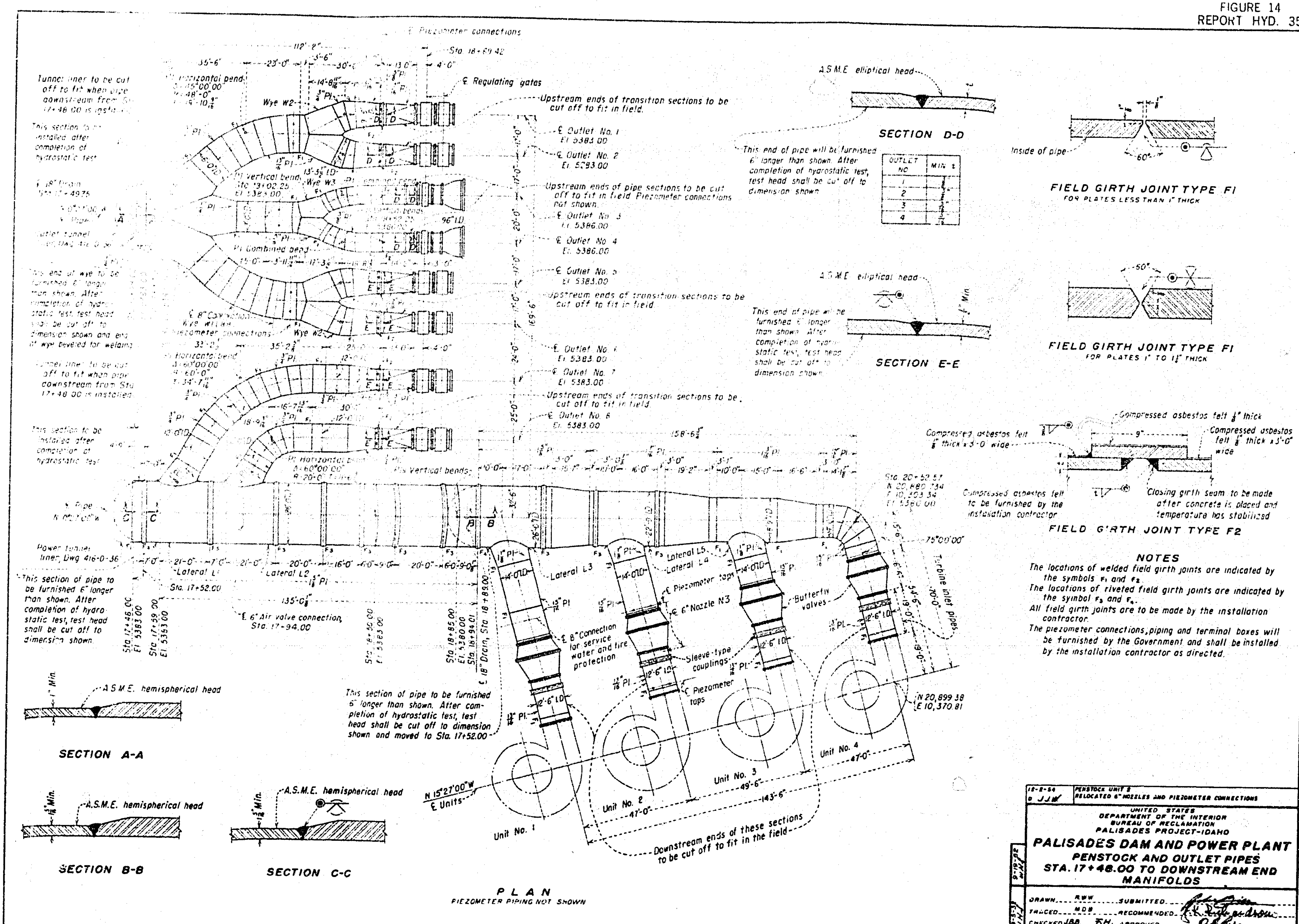
NOTES
Sufficient wall height was used on the model to prevent overtopping.
Stationing is distance along penstock centerline.
Data from 1 to 61.82 scale model.

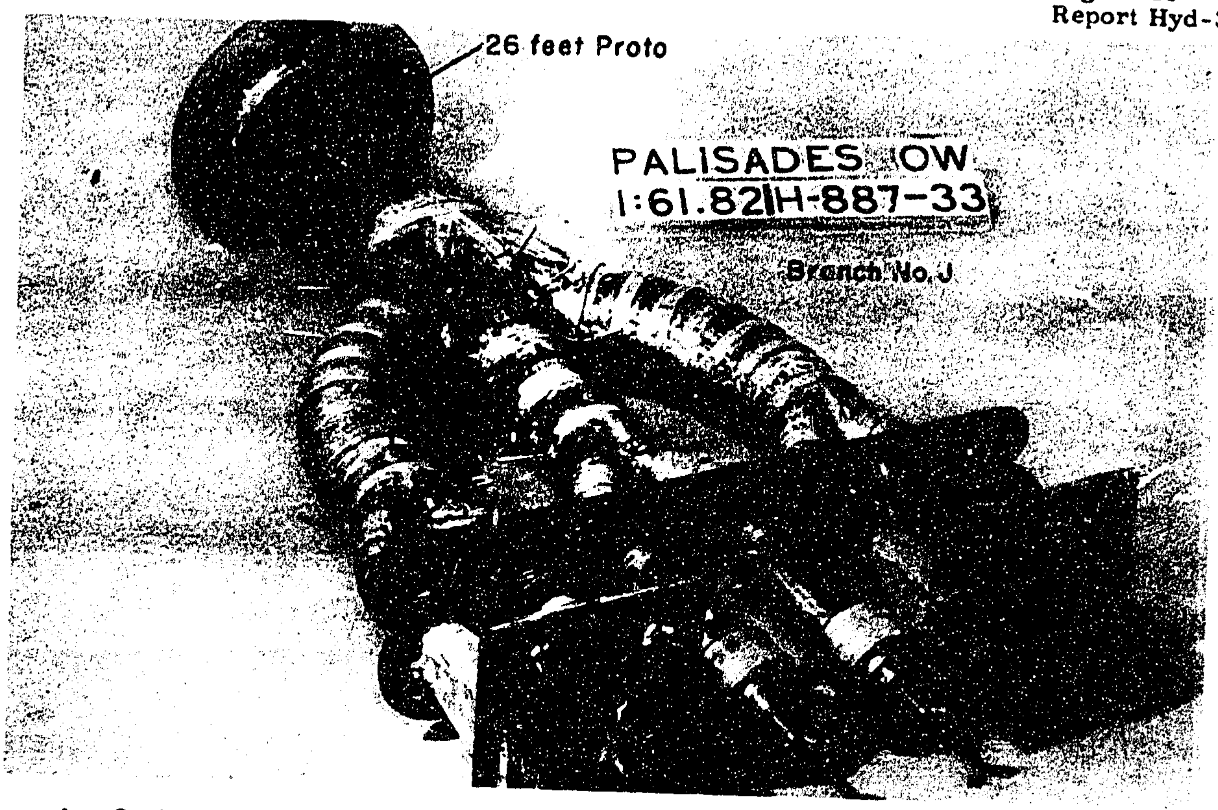
PALISADES DAM
MAXIMUM WATER SURFACE PROFILES IN DIVERSION CHANNEL LININGS WITH VARIOUS DEFLECTOR WALLS

FIGURE 11
Report Hyd. 380

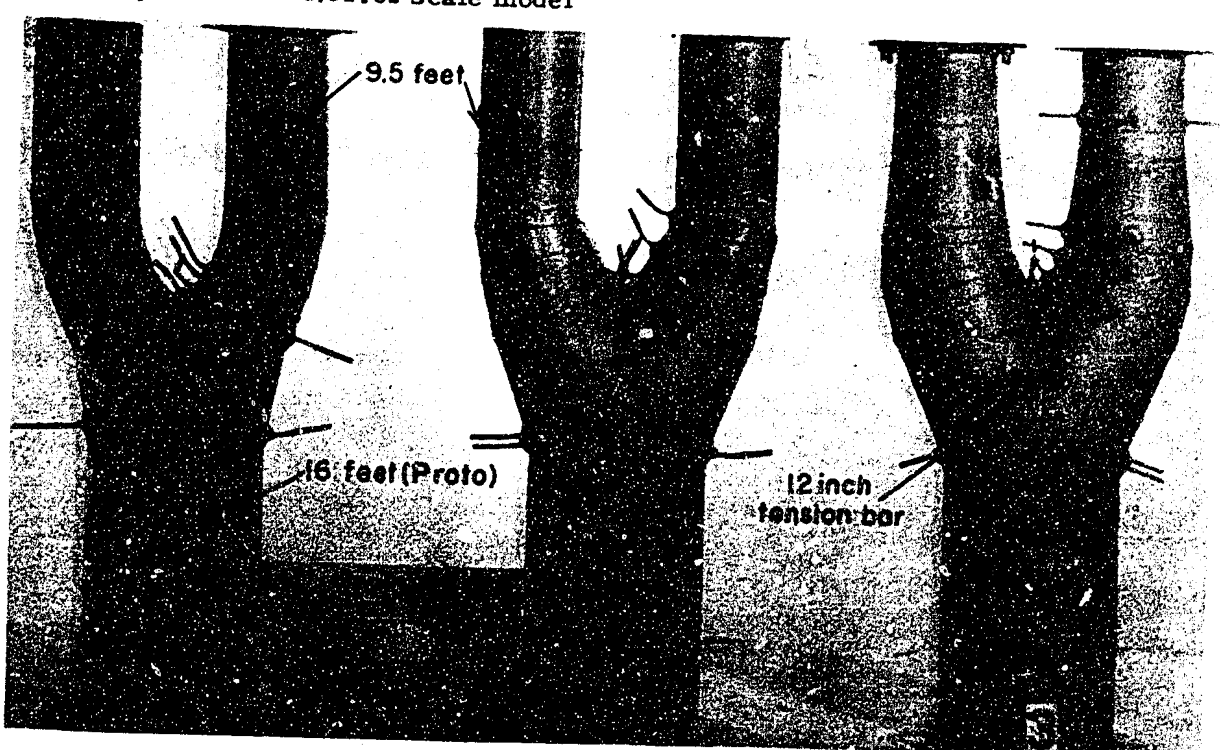
345

FIGURE 14
REPORT HYD. 350





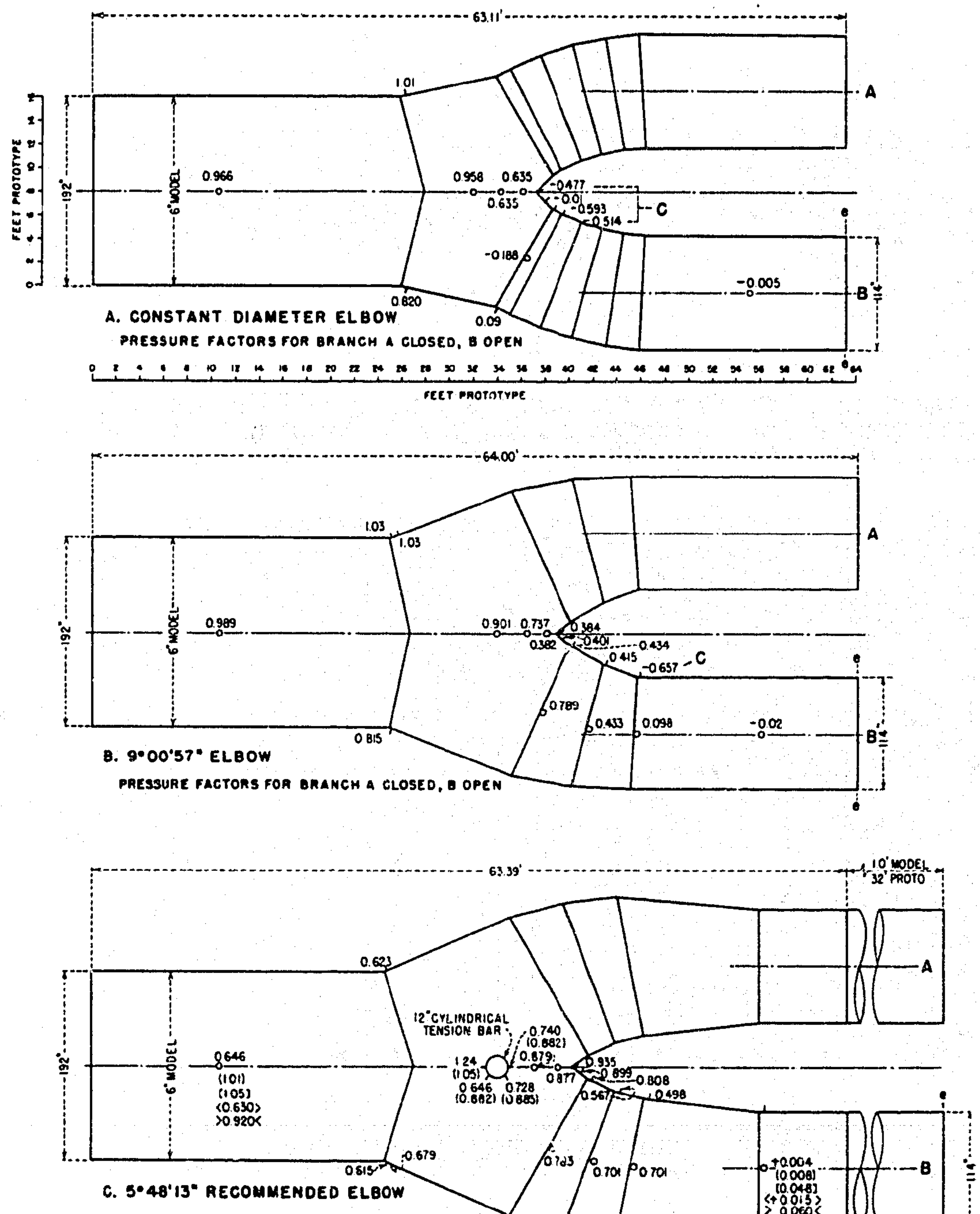
A. Outlet tunnel piping system with 4 slide gates and 2 hollow jet valves - 1:61.82 scale model



B. Two-way Y-branches: (1) Preliminary design with constant diameter passages, (2) 9° 00' 57" converging passages, (3) Recommended design with 5° 48' 13" converging passages, 1:32 scale model

PALISADES DAM

OUTLET WORKS PIPING SYSTEM AND TWO-WAY Y-BRANCH DESIGNS



PRESSURE FACTORS FOR BRANCH A AND B OPEN

( ) FOR BRANCH A CLOSED, B OPEN

[ ] FOR BRANCH A CLOSED, B OPEN AND 2.0' OF PIPE DOWNSTREAM OF C

< > FOR A AND B OPEN - NO TENSION BAR

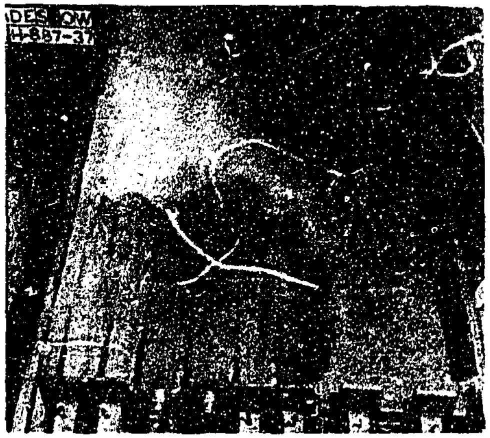
> < FOR BRANCH A OPEN, B CLOSED - NO TENSION BAR

$$\text{PRESSURE FACTOR} = \frac{\text{HEAD AT PIEZOMETER} - \text{HEAD AT e}}{\text{VELOCITY HEAD AT e-e}} = \frac{h - h_e}{V_e^2/2g}$$

PALISADES DAM

PIEZOMETER LOCATIONS AND PRESSURE FACTORS ON TWO-WAY Y BRANCHES

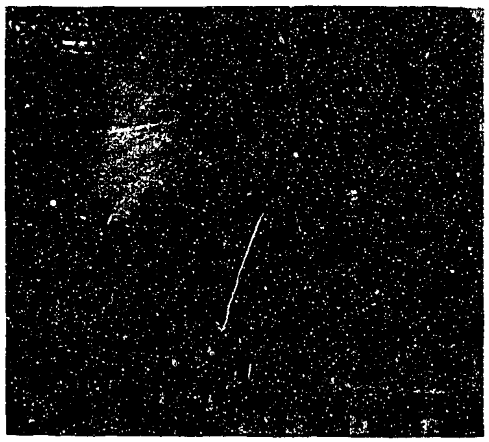
1:32 SCALE MODEL



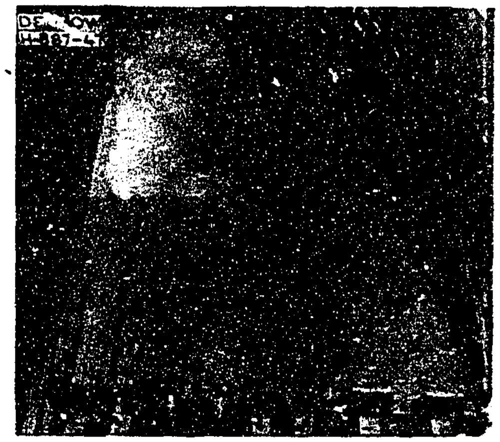
A. Four gates and two valves discharging 31,600cfs - Tailwater elevation 5382.0 Dividing wall removed

B. Two valves discharging 8000 cfs - Tailwater elevation 5377.0

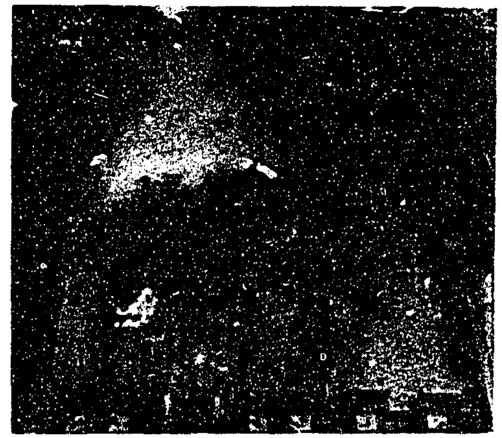
C. Two valves and outer left gate discharging 15,500 cfs - Tailwater elevation 5379.0



D. Two valves and adjacent left gate discharging 15,500 cfs - Tailwater elevation 5379.0



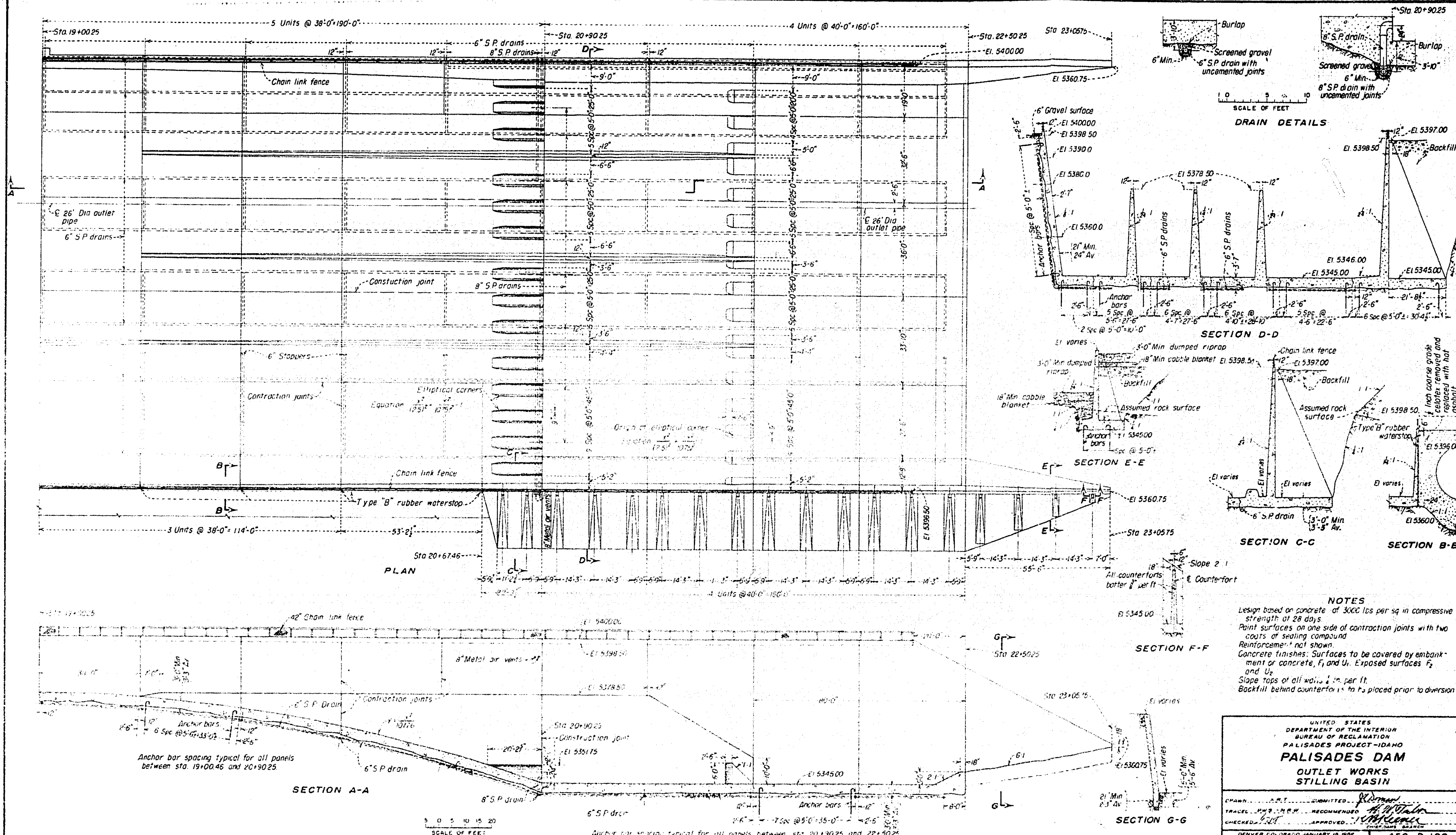
E. Two valves and two left gates discharging 23,400 cfs - Tailwater elevation 5380.0

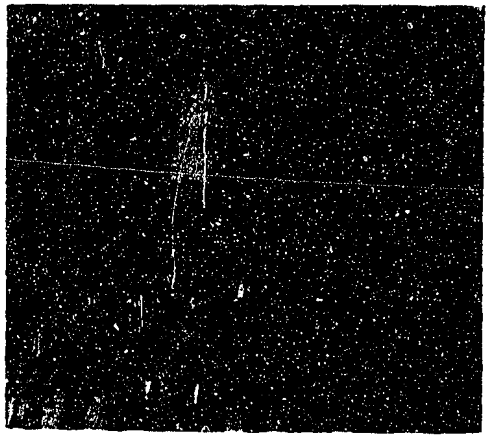


F. Two valves and adjacent right-hand left gates discharging 23,400 cfs - Tailwater elevation 5380.0

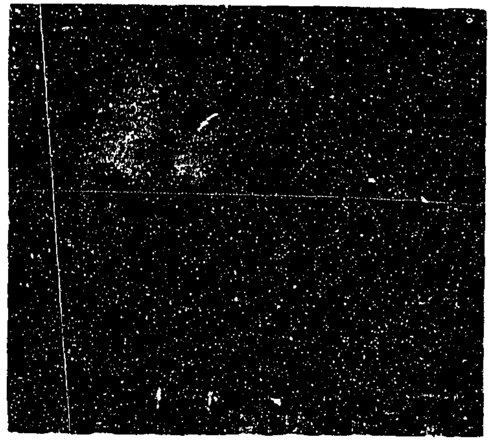
PALISADES DAM
FLOW CONDITIONS IN PRELIMINARY OUTLET WORKS STILLING BASIN WITH RECOMMENDED OUTLET PIPING
1:61.82 scale model

FIGURE 18
REPORT HYD. 350

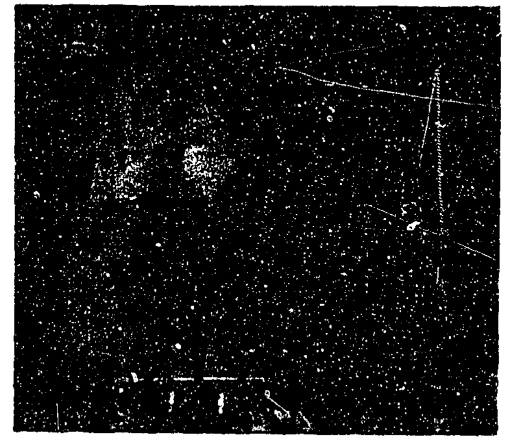




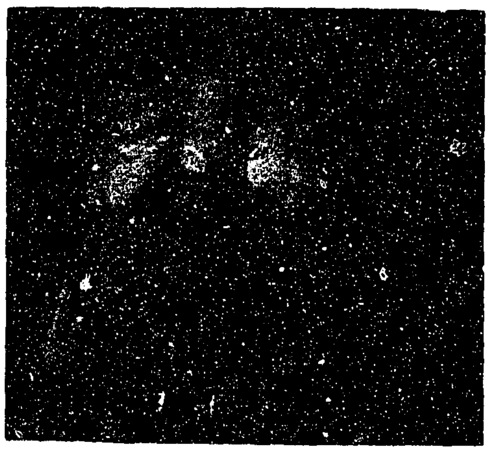
A. Two valves discharging 8000 cfs - Tailwater elevation 5377



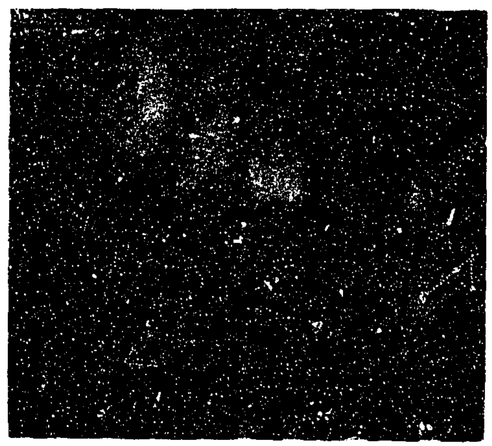
B. Two valves and outer left gate discharging 15,500 cfs - Tailwater elevation 5379



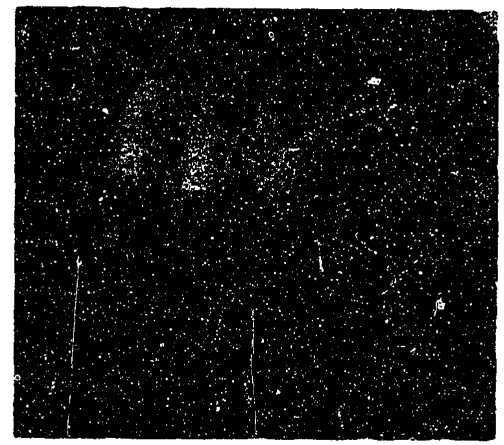
C. Two valves and adjacent left gate discharging 15,500 cfs - Tailwater elevation 5379



D. Two valves and adjacent right and left gates discharging 23,400 cfs - Tailwater elevation 5380.0



E. Two valves, two left gates, and adjacent right gate discharging 28,000 cfs - Tailwater elevation 5381.0



F. Two valves and four gates discharging 31,600 cfs - Tailwater elevation 5382

PALISADES DAM

FLOW CONDITIONS IN RECOMMENDED OUTLET WORKS STILLING BASIN WITH RECOMMENDED OUTLET PIPING
1:61.82 scale model

A. 2 left slide gates and 2 hollow jet valves of outlet tunnel system operating at 23,100 cfs - Tailwater elevation 5379.1

B. Riverbed after 3 hours model operation at 14,700 cfs released through 2 left outlet works slide gates - Tailwater elevation 5377.2

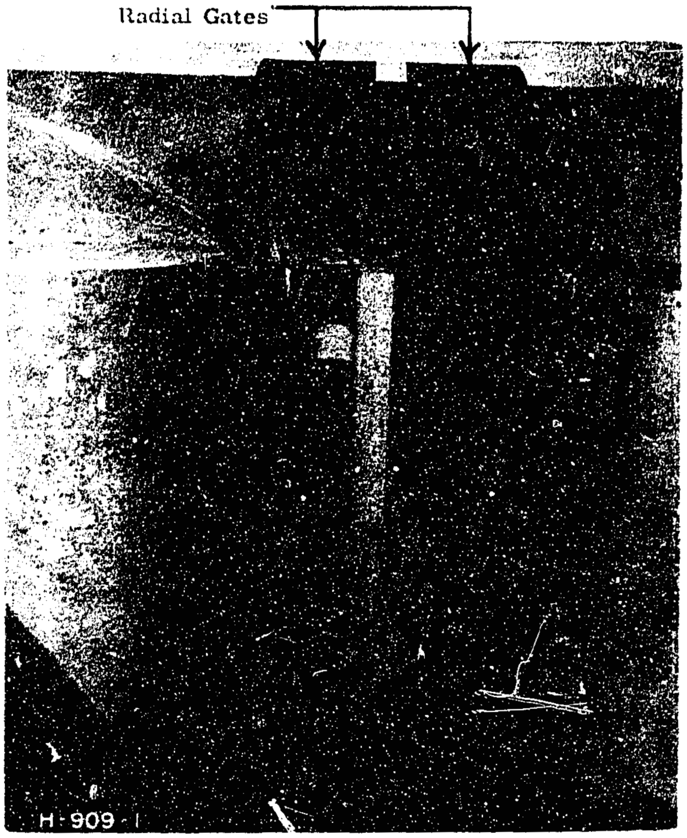
C. Power tunnel outlets operating at a discharge representing 14,700 cfs - Tailwater elevation 5377.2

D. Riverbed after 3 hours model operation at 14,700 cfs

PALISADES DAM

FLOW CONDITIONS AND EROSION FOR OUTLET AND POWER TUNNELS OPERATING AT DISCHARGES REPRESENTING 23,400 CFS AND 14,700 CFS
1:61.82 scale model

Figure 22
Report Hyd-350



A. Preliminary design spillway entrance

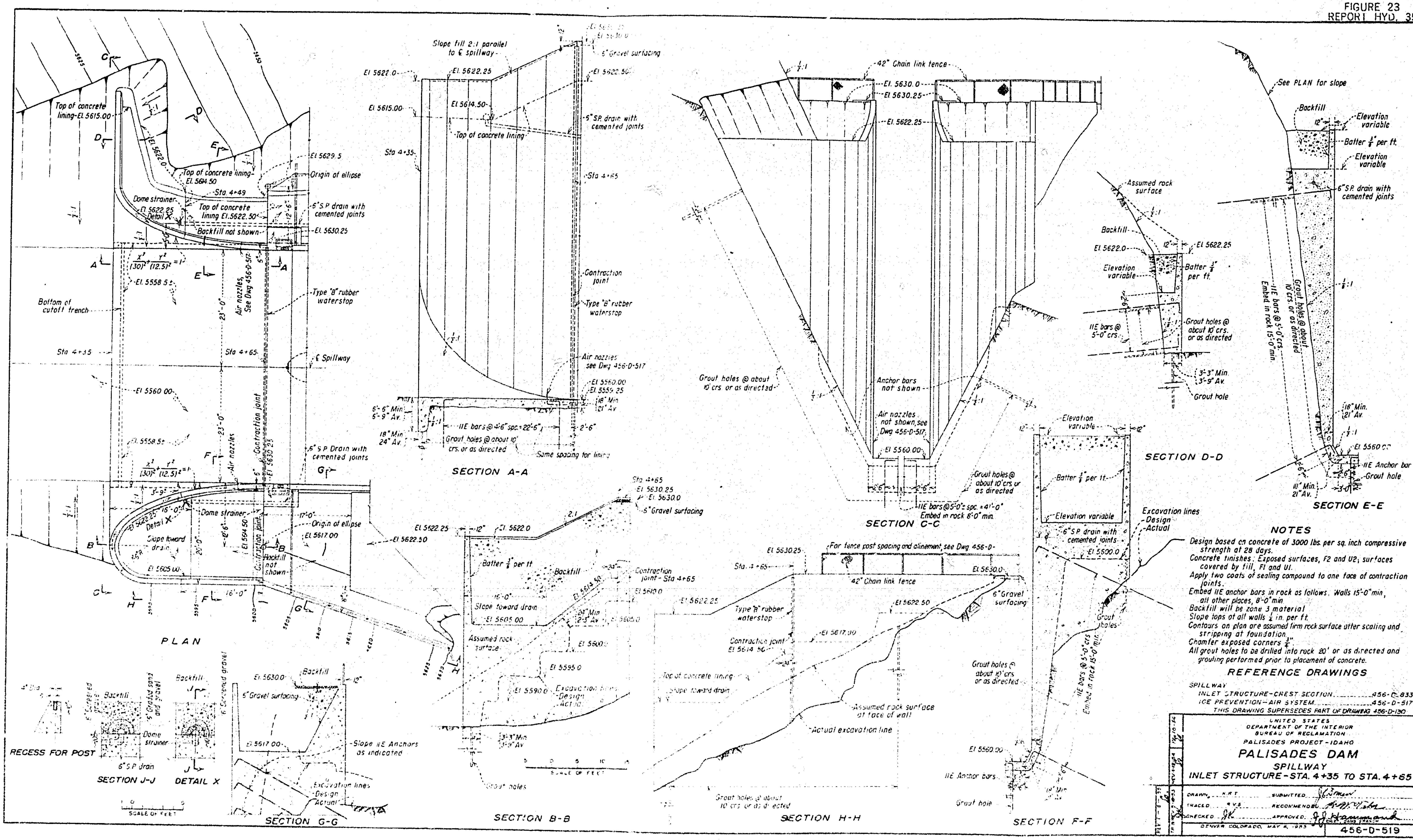
B. Preliminary design spillway exit channel

C. Preliminary spillway entrance operated submerged due to 26-foot diameter tunnel filling. Q = 46,800 cfs., reservoir elevation = 5621.0

D. Water overtopping walls of exit channel at 46,800 cfs

PALISADES DAM

FLOW CONDITIONS IN PRELIMINARY SPILLWAY ENTRANCE AND EXIT CHANNEL
1:61.82 scale model



NOTES

Design based on concrete of 3000 lbs. per sq. inch compressive strength at 28 days.
Concrete finishes: Exposed surfaces, F2 and U2; surfaces covered by fill, F1 and U1.
Apply two coats of sealing compound to one face of contraction joints.
Embed 11E anchor bars in rock as follows: Walls 15'-0" min, all other places, 8'-0" min.
Backfill will be zone 3 material
Slope tops of all walls $\frac{1}{4}$ in. per ft.
Contours on plan are assumed firm rock surface after scaling and stripping at foundation.
Chamfer exposed corners $\frac{3}{4}$".
All grout holes to be drilled into rock 20' or as directed and grouting performed prior to placement of concrete.

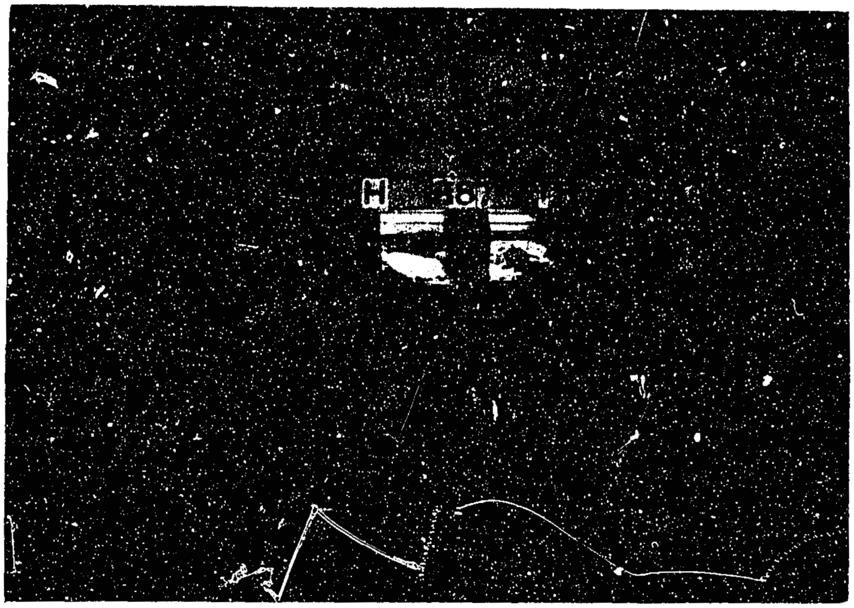
REFERENCE DRAWINGS

SPILLWAY
INLET STRUCTURE-CREST SECTION 456-D-833
ICE PREVENTION-AIR SYSTEM 456-D-517
THIS DRAWING SUPERSEDES PART OF DRAWING 456-D-130

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PALISADES PROJECT-IDAHO

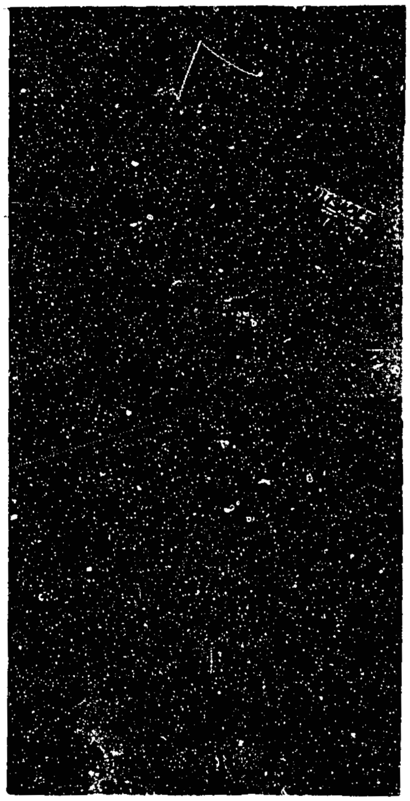
PALISADES DAM
SPILLWAY
INLET STRUCTURE-STA. 4+35 TO STA. 4+65

DRAWN R.R.T. SUBMITTED [signature]
TRACED R.V.S. RECOMMENDED [signature]
CHECKED [signature] APPROVED J. J. Hammond
CHIEF, DAMS BRANCH
DENVER, COLORADO, MAY 8, 1953
456-D-519



A. Recommended spillway entrance with elliptical piers - Both gates full open

B. Flow through inclined shaft - 28-foot diameter tunnel - Both gates full open

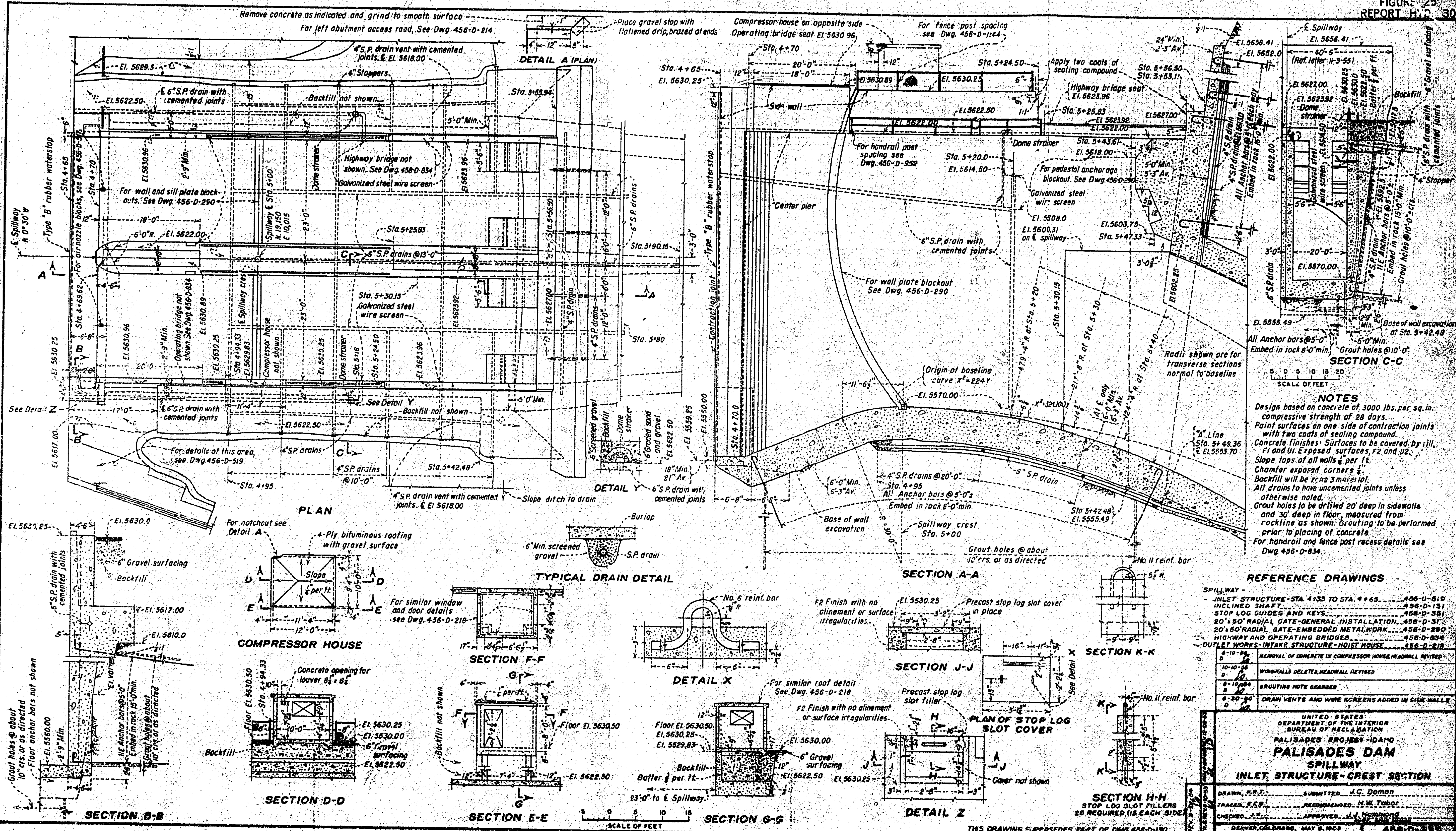


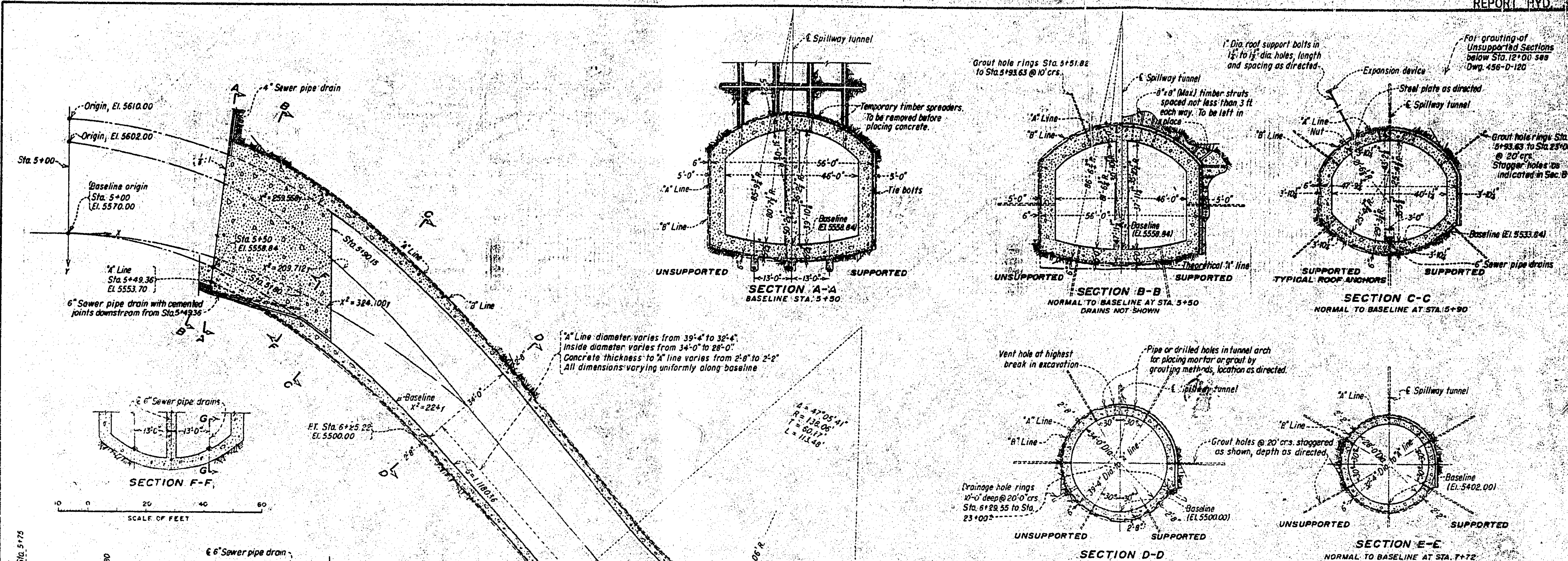
C. Flow in exit channel - Tailwater elevation 5386.0

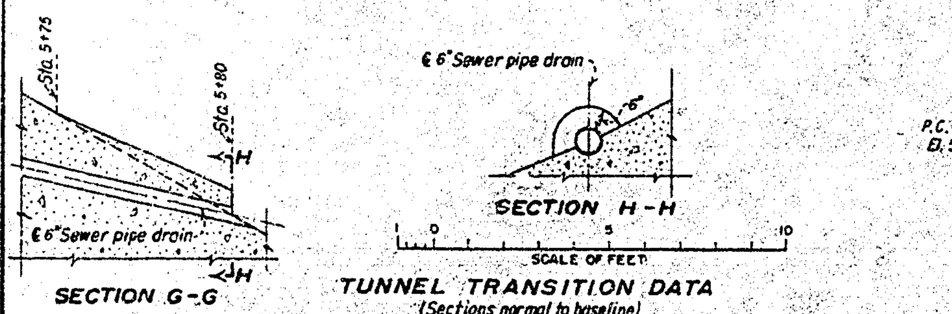
PALISADES DAM

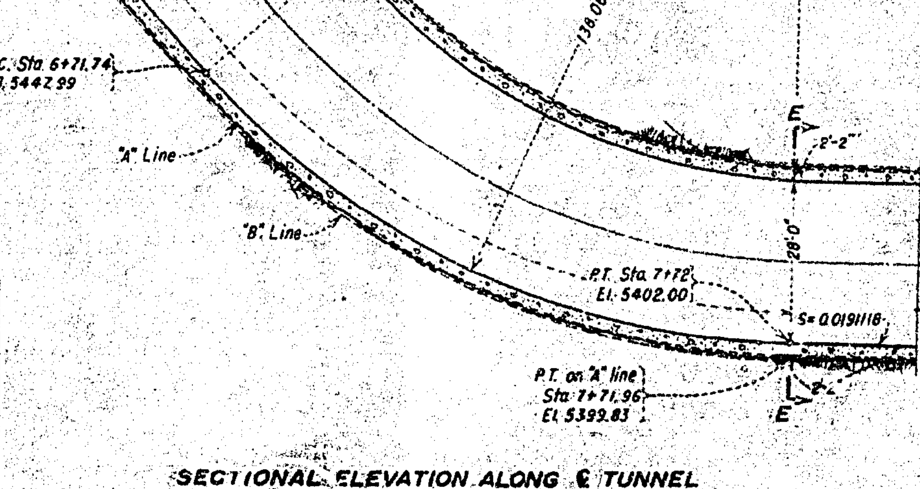
SPILLWAY OPERATION WITH RECOMMENDED ENTRANCE, 28-FOOT DIAMETER TUNNEL, AND RECOMMENDED TUNNEL EXIT TRANSITION - 48,000 CFS DISCHARGE
1:61.82 scale model

FIGURE 25
REPORT HYD 305









TUNNEL TRANSITION DATA

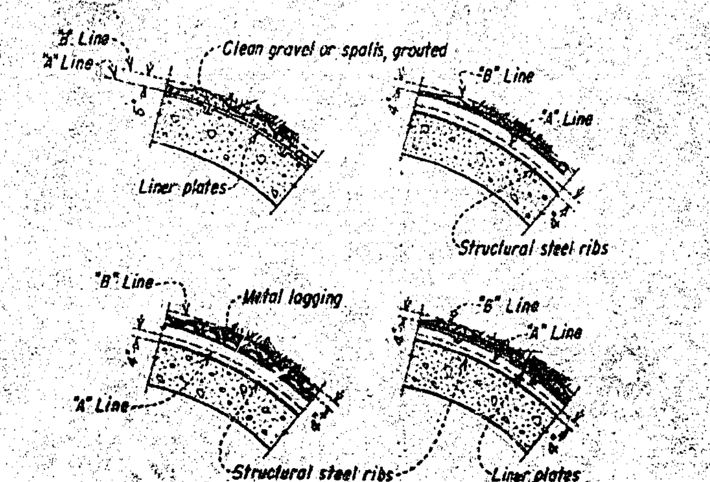
(Sections normal to baseline)

BASELINE		BOTTOM RADIUS		TOP RADIUS		TUNNEL WIDTH		TUNNEL HEIGHT		CONCRETE THICKNESS TO "A" LINE†
STATION	ELEVATION	CONCRETE SURFACE	"A" LINE	CONCRETE SURFACE	"A" LINE	CONCRETE SURFACE	"A" LINE	CONCRETE SURFACE	"A" LINE	
*5+50	5558.84	80'-7¼"	85'-9¾"	31'-0⅝"	36'-2⅝"	46'-0"	56'-0"	39'-10⅛"	50'-2⅞"	5'-2⅜"
5+50	5558.84	81'-6⅝"	86'-6⅝"	30'-10⅝"	35'-10⅝"	46'-0"	56'-0"	37'-11⅞"	47'-11⅞"	5'-0"
5+60	5553.93	55'-5⅞"	60'-2⅞"	27'-11⅞"	32'-6¼"	44'-7⅞"	54'-0⅞"	37'-3½"	46'-9"	4'-8⅜"
5+70	5548.12	40'-5⅞"	44'-10⅝"	25'-5⅞"	29'-1½"	43'-2"	52'-0⅞"	36'-7⅛"	45'-6½"	4'-5⅜"
5+80	5541.43	31'-8⅞"	35'-4⅜"	23'-4¼"	27'-5⅛"	41'-8"	49'-11⅞"	36'-0⅞"	44'-4½"	4'-1½"
5+90	5533.84	25'-4⅞"	29'-3⅝"	21'-6⅛"	25'-4⅞"	40'-1⅞"	47'-9⅞"	35'-5⅞"	43'-2½"	3'-10⅛"
6+00	5525.36	21'-7⅞"	25'-1⅝"	19'-11⅞"	23'-8⅞"	38'-5⅞"	45'-6⅞"	34'-11⅞"	42'-0⅝"	3'-6⅝"
6+10	5515.98	19'-1⅞"	22'-4⅜"	18'-7⅞"	21'-10"	36'-9"	43'-1⅞"	34'-6⅞"	40'-11⅞"	3'-2⅞"
6+20	5505.71	17'-6⅞"	20'-4⅞"	17'-6⅞"	20'-4⅞"	34'-11⅞"	40'-8⅞"	34'-2"	39'-10⅞"	2'-10⅞"
6+25.22	5500.00	17'-0"	19'-8"	17'-0"	19'-8"	34'-0"	39'-4"	34'-0"	39'-4"	2'-8"

*Section A-A on ½:1 slope
†Varies uniformly with respect to distances measured along baseline

REFERENCE DRAWINGS

SPILLWAY AND OUTLET WORKS-GENERAL PLAN AND SPILLWAY SECTIONS 456-D-120
SPILLWAY-INLET STRUCTURE-CREST SECTION 456-D-633



TYPICAL TUNNEL SUPPORTS

NOTES

Maximum pressures for pressure grouting adjacent to tunnel lining: Sta. 5+50 to Sta. 5+90, 50 psi; Sta. 5+90 to Sta. 6+71.74, 75 psi; Sta. 6+71.74 to Sta. 23+00, 100 psi.
In any ring of grout holes from Sta. 5+50 to Sta. 6+25.22 grout those at springing first.
Design based on concrete of 3000 lbs. per sq. inch compressive strength at 28 days.
Concrete finishes: above ℄, F2; below ℄, F4, U3; Sta. 6+71.74 to Sta. 7+72, lower semicircumference F4, U3, with special finish.
Location, sizes, types, and spacing of structural steel ribs, liner plates and metal lagging to be as directed.
Reinforcement not shown.
Space between excavated rock surface and liner plates or lagging shall be solidly packed with clean gravel or spalls and pressure grouted.
Grouting around the inclined shaft to be completed before drains are placed in inlet structure crest section.
Distances between crs. of grout hole rings and drainage hole rings are measured along base line.

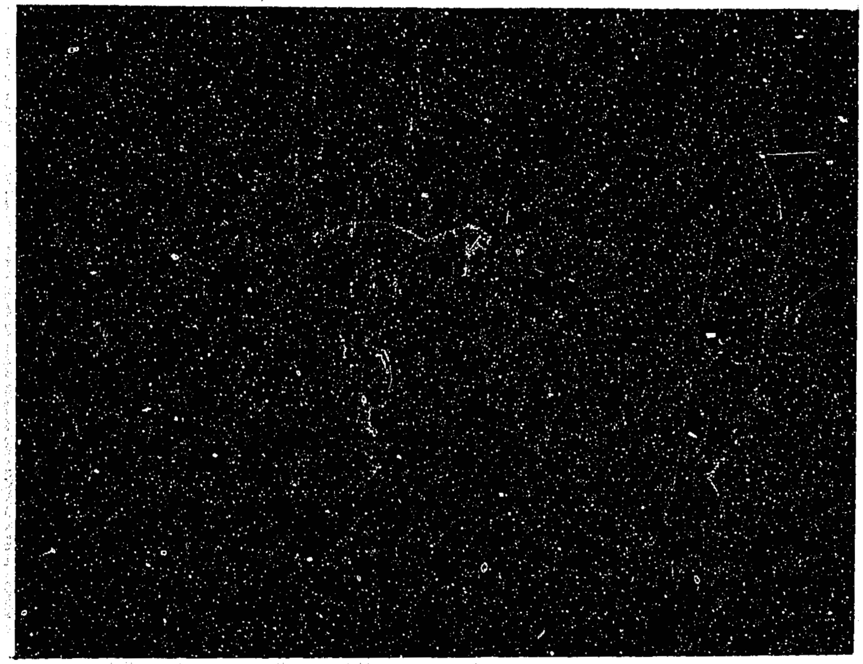
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PALISADES PROJECT - IDAHO

PALISADES DAM
SPILLWAY
INCLINED SHAFT

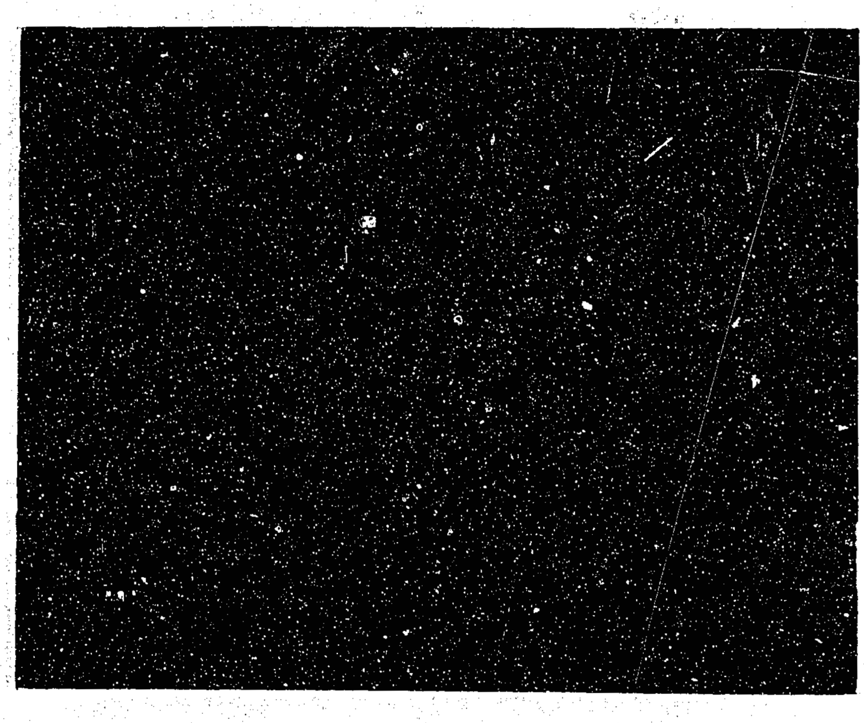
DENVER, COLORADO, JAN. 13, 1953

456-D-151

NOTES REVISED



A. Spillway entrance - Flow through right-hand gate - Recommended elliptical piers

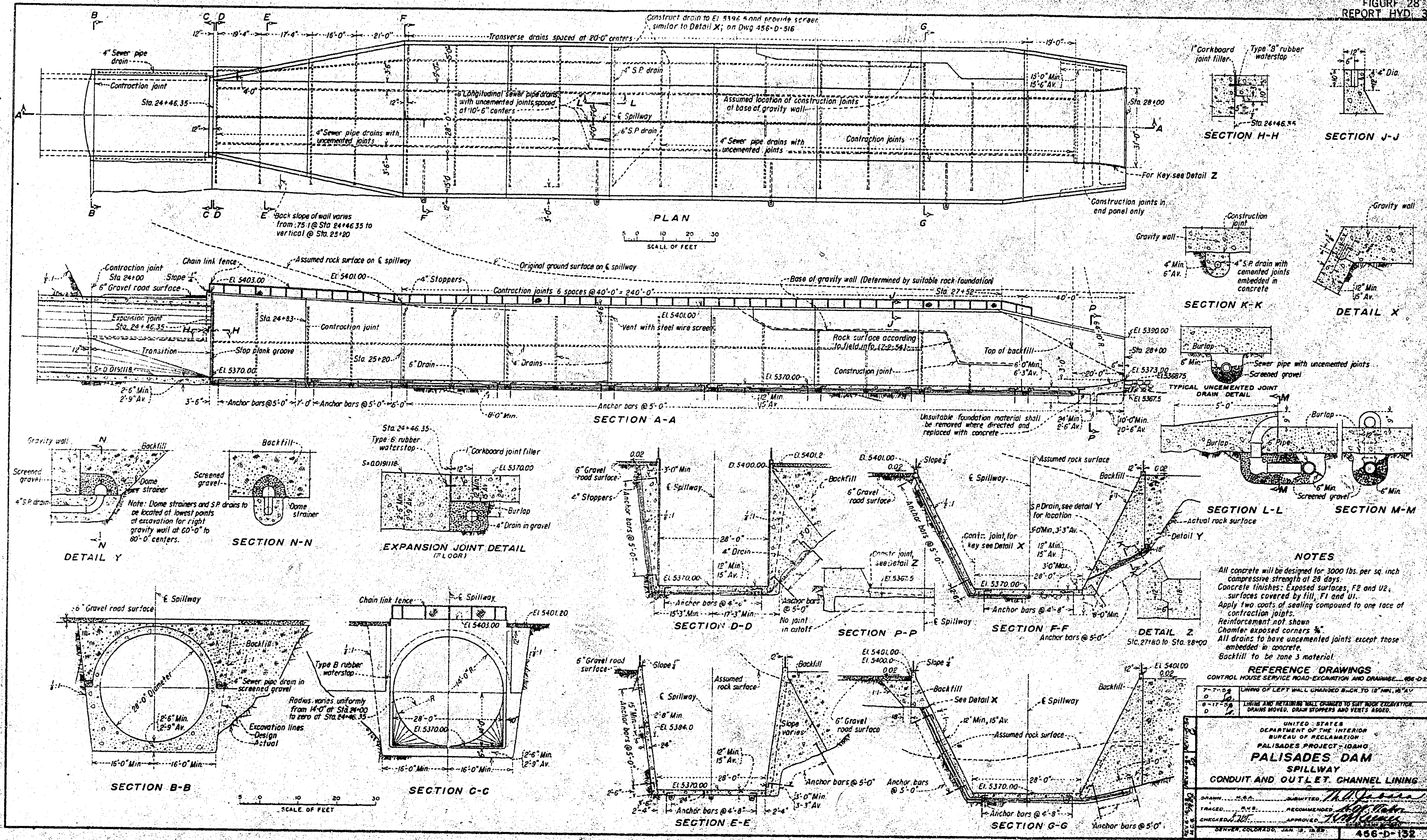


B. Flow through inclined shaft - 28-foot diameter tunnel - Flow through right-hand gate

PALISADES DAM

OPERATION OF RECOMMENDED SPILLWAY WITH FLOW THROUGH ONE GATE - 25,000 CFS. DISCHARGE
1:61.82 scale model

FIGURE 28
REPORT HYD. 350



Operation of spillway and outlet works at a discharge of 94,500 cfs - Tailwater elevation 5386.0

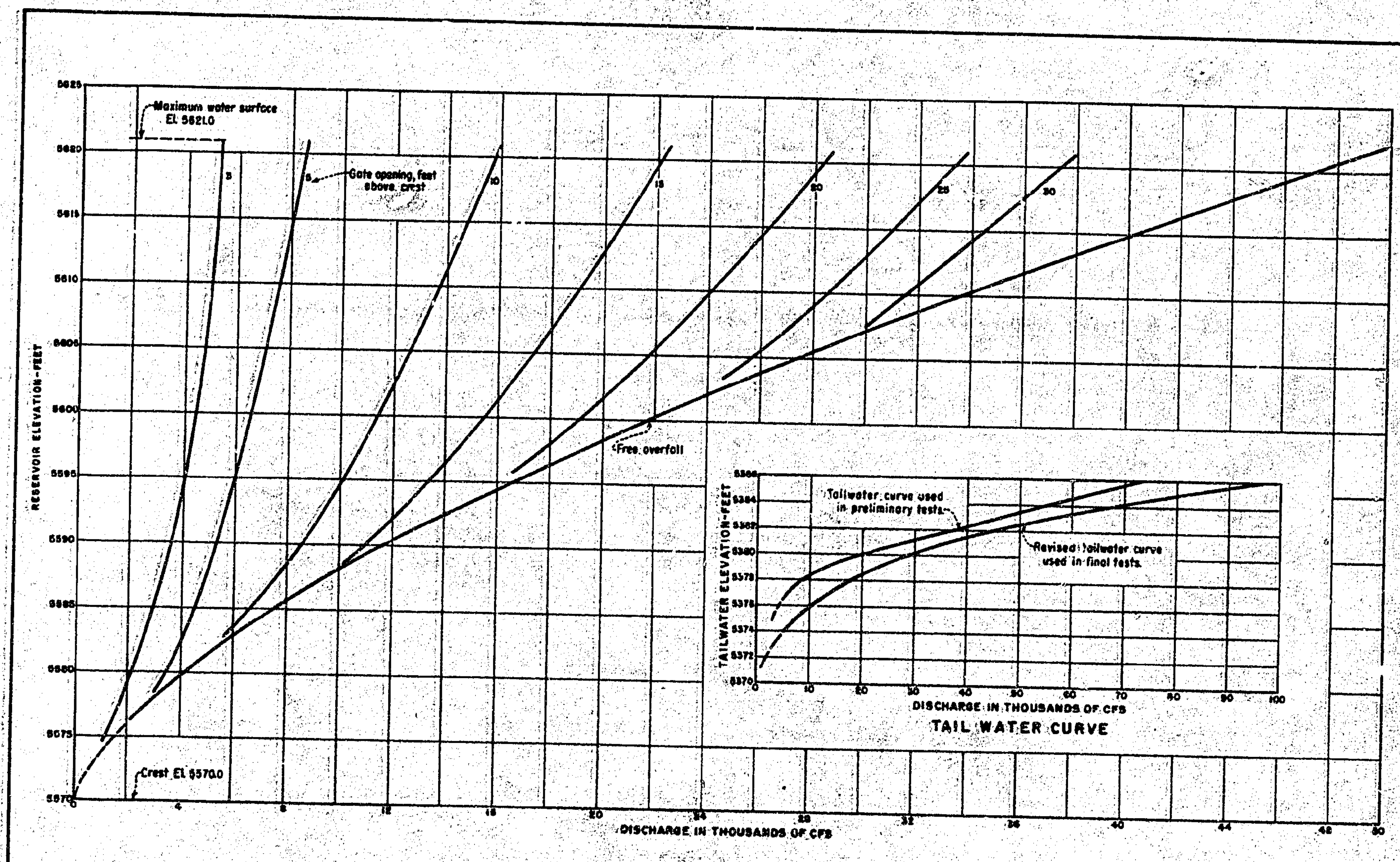
PALISADES DAM

FLOW CONDITIONS FOR MAXIMUM DISCHARGE THROUGH RECOMMENDED SPILLWAY AND OUTLET WORKS
1:61.82 scale model

Erosion after 4 hours model operation at 94,500 cfs - Tailwater elevation 5386.0. Minimum erosion elevation 5300. - Elevation downstream of outlet works 5341.

PALISADES DAM

RIVER CHANNEL EROSION AFTER MAXIMUM DISCHARGE FROM SPILLWAY AND OUTLET WORKS - RECOMMENDED DESIGN
1:61.82 scale model



PALISADES DAM
SPILLWAY CAPACITY AND TAILWATER CURVES
SPILLWAY DATA FROM 1:60.02 SCALE MODEL

FIGURE 31
REPORT HYD. 340